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EVALUATION OF DIFFERENT SEMIVARIOGRAM MODELS IN
GROUNDWATER QUALITY MAPPING USING GIS-BASED SIMPLE KRIGING AT
KHORASAN RAZAVI-IRAN

NG ZONE FHONG

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
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JUNE 2015

SUPERVISOR'S DECLARATION

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STUDENT'S DECLARATION

I hereby declare that this thesis entitled “Evaluation of Different Semivariogram Models in Groundwater Quality Mapping Using GIS-Based Simple Kriging at Khorasan Razavi-Iran” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :
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DEDICATION

A very special dedication to my beloved family members, especially my father (Mr. Ng Choong Ming), my mother (Mrs. Leo Lee Yong), my sister (Miss Ng Kar Yi) and my brother (Mr. Ng Zone Ting)

Unlimited appreciation to all my caring and patience lecturers who gave me lots of knowledge, advices, motivation, time and supports. To all my beloved friends for the supports and the cooperation given. I couldn't have done this without you all.....

Thank you for the Care, Commitment and Encouraged on me and Support although is indirectly involved in this project.

Sincerely
Ng Zone Fhong

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ABSTRACT

A high demand of the water usage at Khorasan Razavi-Iran was supplied from groundwater. The quality of this groundwater was determined by taking samples from 472 of the wells within the study area like SO_4 and pH. This study was about to choose the best fitted semivariogram models to perform the optimum result of the groundwater quality mapping by using point interpolation. In addition, this research also can show about the estimation accuracy versus the lag distance. The GIS-based software, ILWIS 3.4 was used for geostatistical analysis and generation of the groundwater quality map. The pixel size and lag distance used was 100m. An interpolation technique, Simple Kriging (SK), was applied to obtain the spatial distribution of groundwater quality parameters. In the result, the estimated semivariogram values were the best fitted semivariogram models that were Rational Quadratic model for SO_4 and the Exponential model for pH. Evaluation of these semivariogram models and the estimation accuracy of SK methods was by Coefficient of Determination (R^2), Nash-Sutcliffe Model Efficiency (E), and Root Mean Square Deviation (RMSD). For SO_4 in Rational Quadratic model, it was 0.95 for R^2 which represent the highest value among others model, 0.95 for E which represent the highest also and 1.67 for RMSD which indicate the lowest error from the rest model. On the other hand, the predicted error for pH in Exponential model was 0.78 for R^2 ; 0.77 for E and the last was 0.18 for RMSD. Furthermore, the accuracy trend was illustrated in table form and figures that the error of the accuracy is getting worse for example the R^2 for SO_4 in 500m lag with 0.96 was become lesser in 1500m that is 0.69. For the E from 500m to 1500m, the value was lesser as well as RMSD was increased due to the distance. All in all, the objectives were accepted.

ABSTRAK

Permintaan yang tinggi pada penggunaan air di Khorasan Razavi-Iran adalah dibekalkan dari air bawah tanah. Kualiti air bawah tanah ini telah dikumpulkan dengan mengambil sampel dari 472 buah telaga di dalam kawasan kajian seperti SO_4 dan pH. Objektif kajian ini adalah untuk memilih model semivariogram yang terbaik untuk melaksanakan keputusan yang optimum untuk pemetaan kualiti air bawah tanah dengan menggunakan titik interpolasi. Di samping itu, kajian ini juga boleh menunjukkan tentang ketepatan anggaran berbanding jarak lag. Perisian berasaskan GIS, ILWIS 3.4 telah digunakan bagi analisis Geostatistik dan penjanaaan peta kualiti air bawah tanah. Saiz piksel dan jarak lag digunakan ialah 100m. Teknik interpolasi, 'kriging mudah' (SK), telah digunakan untuk mendapatkan taburan parameter kualiti air bawah tanah. Untuk hasil didapati, nilai semivariogram dianggarkan terbaik dipasang dalam model ialah rasional kuadratik model bagi SO_4 dan model Eksponen merupakan model yang terbaik bagi pH. Penilaian model semivariogram dan ketepatan anggaran dalam kaedah SK adalah dengan Pekali Penentuan (R^2), Kecekapan Nash-Sutcliffe Model (E), dan Root Mean Square Sisihan (RMSD). Untuk SO_4 dalam model kuadratik rasional, ia memberi nilai 0.95 adalah untuk R^2 di mana merupakan nilai tertinggi di kalangan model lain, E adalah 0.95 di mana nilai yang tertinggi juga dan RMSD adalah 1.67 iaitu kesilapan yang paling rendah daripada model yang lain. Seterusnya, kesilapan yang diramalkan untuk pH dalam model Eksponen adalah 0.78 untuk R^2 , E adalah 0.77 dan RMSD adalah 0.18. Selain itu, trend ketepatan itu digambarkan dalam bentuk jadual dan angka bahawa kesilapan ketepatan semakin teruk di mana R^2 untuk SO_4 dengan 500m lag ialah 0.96 telah menjadi lebih kecil dengan 1500m lag iaitu 0.69. Bagi E dari 500m hingga 1500m lag, nilai itu telah menjadi semakin kecil di samping RMSD telah meningkat disebabkan oleh jarak meningkat. Oleh itu, semua objektif telah diterima.

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LIST OF ABBREVIATIONS

GIS	Geographical Information System
WEPA	Water Environment Partnership in Asia
ILWIS	Integrated Land and Water Information System
IDW	Inverse Distance Weighting
OK	Ordinary Kriging
SK	Simple Kriging
AK	Anisotropic Kriging
UK	Universal Kriging
CK	Co-Kriging
GNU	General Public License
JMG	Minerals & Geoscience Department Malaysia

LIST OF SYMBOLS

MLD	Million liter per day
SO ₄	Sulphate
pH	Negative log of the activity of the hydrogen ion in an aqueous solution
km ²	Kilometer square
Ca ²⁺	Calcium
Na ⁺	Sodium
Mg ²⁺	Magnesium
Cl ⁻	Chloride
HCO ₃ ⁻	Bicarbonate
NO ₃	Nitrate
TDS	Total dissolved solids
UV	Ultraviolet
ppm	Part per million
mg	Milligram per liter
n	Number of the untried points used to test
y _i	Real values from input
\hat{y}_i	Predicted value from the kriging model
N _h	Number of pairs separated by vector h
h	Lag distance
x _i	The starting location
x _i +h	The ending location

γ	The only dependent on the length of lag distance but not its direction
R^2	Coefficient of determination
E	Nash–Sutcliffe model efficiency coefficient
RMSD	Root mean square deviation
N	Number of observations used to fit the model
Σ	Summation symbol
\bar{x}	Mean x value
y_i	Y value for observation i
\bar{y}	Mean y value
σ_x	Standard deviation of x
σ_y	Standard deviation of y
X_{obs}	Observed values
X_{model}	Modelled values at time/place i
u, u_α	Location vectors for estimation point and one of the neighbouring data points, indexed by α
$n(u)$	Number of data points in local neighbourhood used for estimation of $Z^*(u)$
$m(u), m(u_\alpha)$	Expected values (means) of $Z(u)$ and $Z(u_\alpha)$
λ_α	Kriging weight assigned to datum $Z(u_\alpha)$ for estimation location u ; same datum will receive different weight for different estimation location.

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF PROPOSED STUDY

Groundwater is a hidden source of water supply because it remains in the subsurface of earth. To date, groundwater is the vital source of freshwater. The raise on the freshwater demand for irrigation, industrial purpose, drinking water and domestic water supply has become the main factors on the groundwater exploitation. However, groundwater is still the least utilized sources compared to the surface water resources such as lakes, Perennial River and rainfall. There are many potential spots of groundwater where can make use of them in the process of clean water. To be safe in the process of clean water making, the quality of the groundwater is the priority issue before it can be consumed (Ibrahim *et al.*, 2012).

Groundwater is normally high in quality. After being filtered naturally via the different layers of soil properties, a colourless, clear and free from microorganism contaminated water formed, but the groundwater is always maintained in such excellent quality properties. As a result, the groundwater quality assessment is crucial to the nation so that a better quality of clean water for drinking, domestic use and so on.

Geographical Information System (GIS) is a powerful tool to help on the prediction of the natural resources and environmental problems for example the groundwater quality. There are many different applications of GIS in the groundwater studies, like groundwater

movement modelling, site suitability analyses, groundwater quality assessment with spatial data for prediction purpose (Nas and Berktaş, 2010).

In GIS application, all the spatial data is going to be analyzed by Kriging method, a method of interpolation which helps in estimation and unknown value prediction from data collected at specific study area. In addition, this method has a benefit to minimize the error of predicted values which are estimated by spatial distribution. Kriging uses semivariogram to show the spatial variation. The main problem of Kriging is to choose the best fitted semivariogram model, which affect the spatial interpolation accuracy of the groundwater quality mapping. There are many different types of semivariogram model such as Circular model, Spherical model, Exponential model, Gaussian model, and so on (Huang *et al.*, 2012).

A semivariogram is one of the significant functions to show the spatial correlation in observations measured in sample of the study area. It is represented as a graph that shows the semi variance in measure with distance or average lag between all pairs of sampled locations. By producing this graph, a mathematical model that describes the variability of the measure with location can be built. Modeling of the relationship between sample locations to indicate the variability of the measure with distance of separation is called semivariogram modeling. It is applied to applications involving estimating and the predicted value of a measure around the new location. Semivariogram modeling is also called as semivariogram modeling (Gandhi, 2012).

1.1 PROBLEM STATEMENT

There are too many different types of semivariogram models in kriging interpolation analysis. There are all together six different types of semivariogram models to be tested to determine which the best fitted semivariogram model is based on SO₄ and pH in the generation of groundwater quality map. Besides that, there are also various kind of Kriging method to deal with different situations or problems.

In the year 2010, Malaysia water demand was increased abruptly to approximately 17,000 MLD as our country's population achieves 30 million. There are almost 98% of water consumed from the surface water resources now in Malaysia. Due to the excessive used of water resources on the surface water, it may cause the water resources unsustainable and quick action must be taken to overcome this problem (Darby, 2009).

Surface water resources are directly exposed to the environment, thus they are likely to be affected by the land use factors, individual behavior and also the extreme weather condition. Therefore, groundwater is the best option to replace the in danger resources since it is a sustainable and reliable water source as long as it is extracted in a right way by using appropriate technology and steps. This problem must be taken into consideration for future prospect and to be concerned with, all the respective organizations so that our nation have a better water supply.

1.2 RESEARCH OBJECTIVE

The objectives of this study are:-

- To determine the best fitted semivariogram model to determine spatial variations of groundwater quality based on the SO_4 and pH.
- To determine the trend of error propagation in interpolation of groundwater quality data from the point sources.

1.3 SCOPE OF PROPOSED STUDY

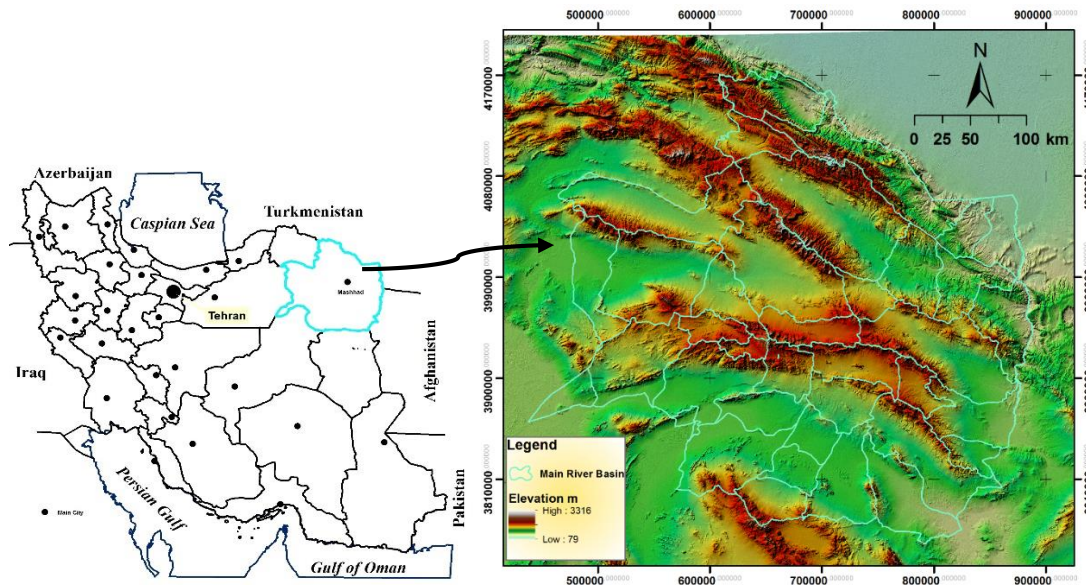


Figure 1.1: The locality map of the Khorasan Razavi-Iran

Source: Akbari (2014)

There are 472 wells coordinate and their respective groundwater quality parameters, data which are SO_4 and pH being selected in this research. The groundwater quality parameter is based on the pH value and Sulphate (SO_4) in the year of 2012.

The software for the spatial interpolation is called ILWIS 3.4, a vector and raster processing, GIS-based free download software (Bhd, 2011). It is used for point interpolation by using Simple Kriging. The pixel information and the lag distance used was 100m.

The Khorasan Razavi province is located in the north-eastern part of Iran (Figure 1.1). Approximately, this province is 127432 km², and its population is estimated at over 6047000. This city mainly relied on groundwater resources as their daily purpose, for example, irrigation, domestic purpose, drinking and industrial purpose.

1.4 EXPECTED OUTCOME

- To obtain the best fitted semivariogram model in the spatial variation of groundwater quality based on the SO₄ and pH.
- To check the trend of error propagation in interpolation of groundwater quality data from the point sources.

1.5 SIGNIFICANCE OF STUDY

The first importance of this study is to select the best fitted semivariogram model for kriging interpolation which can be evaluated by the estimation error measure such as the Coefficient of determination, R²; Nash–Sutcliffe model efficiency coefficient, E, and Root-mean-square deviation, RMSD. The best semivariogram models in groundwater quality mapping can be known according to different kind of water quality parameters. It can help the next researcher to choose as a control map for comparison. This research has contributed to the water quality modeller on choosing a suitable semivariogram model when undergoing spatial interpolation by Kriging method.

Next, the second importance of this study is to define the capabilities of GIS techniques in order to perform the groundwater quality assessment in a specific watershed area. It is also the best tools assisting in decision making by utilized GIS. For example, in planning and developing scenarios, water quality zonation provide a guideline for future development and may take a better action in groundwater management. It also helps in finding out a better solution for a quick assessment.

1.6 CONCLUSION

In this chapter, the background of proposed study, problem statement, our research objective, the scope of proposed study, the expected outcome of our project, and also the significance of the study have been discusses. In this study, the different semivariogram

model in groundwater quality mapping by using simple kriging method was the main. In this study, we will proceed with our chapter 2, Literature Review.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Groundwater plays a crucial role in drinking water for everyone, especially for those who lives in rural areas. However, it may become dirty and polluted due to the factors of human activities and also natural factors. Different land use such as industrial, agricultural works and many more activities will influence the groundwater quality. These contamination problems may lead to disease, infection, no water supply, economy rise up, and so on (Nas and Berktaş, 2010).

For the physical and chemical condition of groundwater, the best solution need to be found to control the groundwater quality for a better future life. Therefore, a good monitoring network should be shown of both adequate and appropriate information concerning the groundwater quality as well as be effective in terms of cost (Narany *et al.*, 2014).

GIS is being applied in this study and kriging techniques for groundwater quality mapping are used such as simple kriging and ordinary kriging. In this study, Kriging techniques were used to interpolate groundwater parameters pH values and SO₄ in the study area. Besides that, there are many different semivariogram models need to be plotted and selected the best fitted model to increase the accuracy of results obtained.

2.1 GROUNDWATER QUALITY PARAMETERS

According to Resources (2013), groundwater quality standards are the maximum allowable concentrations of pollutants in groundwater which may be tolerated without creating a threat to human health or which would otherwise render the groundwater unsuitable for use as a drinking water source.

Groundwater consists of many different chemical compounds with their respective concentrations. The soluble minerals in soils and sedimentary rocks are the main source of chemical constituents in groundwater (Committee, 2005). There are about 95% of the ionic compound in groundwater like the cations potassium K^+ , calcium Ca^{2+} , sodium Na^+ , magnesium Mg^{2+} as well as the negatively charged chloride Cl^- , sulphate SO_4^{2-} , bicarbonate HCO_3^- and nitrate NO_3^- . The combination of these ions will be same as the total dissolved solids TDS.

The parameters used in this research to determine the quality of the groundwater are pH value, and sulphate SO_4 because they are the fundamental properties in groundwater which were the best water quality indicator among the rest.

2.2 pH VALUES

The pH value of groundwater is a foremost property to declare its alkalinity and acidity. Due to the change of the pH value, it may affect the chemical properties of many organic and inorganic substances dissolved in the groundwater. It is a good indicator for the groundwater usage, for example to determine the suitability for domestic and commercial uses were mainly for drinking purpose. It's also helpful in the balancing of the harmful chemicals through water flow (Baskaran Sundaram and Ross S. Brodie, 2009).

For the chemical properties of the groundwater, it will be dependable to the duration of the groundwater surface contact with the rock or sediment particles. The pH value will be stabilized or act as a buffer by these chemical composition of the bedrock. Therefore, the

time is the only factor which can change the groundwater characteristics. As the time goes by, it will make the rock to be mineralized and yet the pH value will be differ in time because of the different mineral content react with the water itself.

There are 3 parts of results for the pH value. Firstly, the groundwater with 7 is the neutral form of water, which we can know it as a distilled water. If the groundwater has a pH value greater than 7, it is a basic water, whereas it is an acidic water as the pH value is less than 7. Groundwater, which is passing through the carbonate rocks like marbles and limestones will ordinarily possess a pH value less than 7 as the acidic water. These groundwater had gone through a process called neutralisation. Normally, the groundwater will remain it status as an acidic water, although there are few carbonate rocks such as volcanic rocks, sandstones, gneisses, metamorphic granitic schists and so on (Agwt.org, 2003).

2.3 SULPHATE, SO₄

Sulfate ions are considered soluble ions which will dissolve in groundwater that give certain concentration in the water. Many of the sulfate ions are formed when there is the ores undergo an oxidation process. Besides that, these ions also can be found in the industrial wastes. Thus, the direct method of sulphate concentration in groundwater was from the diffusion of industrial waste into the water table. An UV Spectrophotometer was used to measure its concentration. The desirable limit for Sulphate is 200 and 400 mg/l in Permissible limit according to IS: 10500-2012 (Dohare *et al.*, 2014).

There are many minerals that consist of sulphate such as sodium sulfate (Glauber's salt), calcium sulfate (gypsum), and magnesium sulfate (Epsom salt). 1 mg/L is equivalent to 1000th of 1 gram in 1 liter of water, which is approximately same as one part per million (ppm). In addition, 1 ppm is one drop of the sulphate in ten gallons of water. As sulphate in water exceeds 250 mg/L, it will taste bitter which is disaggreable for drinking. There are also many other effects if a high level of sulphate concentration like they may corrode the plumbing especially particularly copper piping (Health, 2014).

Sulphate basically possess a maximum concentration of 50 mg/l in natural waters as well as 1000 mg/l for the water where coal, pyrite, and lignite is contacted or inside the water. It can be classified into 3 different stages for example, poor (0-200 mg/l), good (200-400 mg/l), and bad (>400 mg/l) .

2.4 SPATIAL PATTERN

2.4.1 Geo-Statistic

According to Nas (2009), GIS has greatly benefited based on the natural resources and environmental concerns for example groundwater. Geostatistical analysis was a helpful system to calculate the water variables in space and time.

Besides, geostatistical methods were developed to present spatial correlation models with a semivariogram. The semivariogram is usually found in geostatistics and there is an interpolation method called kriging (Cinnirellaa *et al.*, 2005).

Georges Matheron was the first man developed about geostatistics has made rapid development along the years. Now, geostatistics term has been widely used to describe all the statistics application in hydrogeology and geology where the attribute data is stochastic in space. Geostatistical techniques are frequently used to calculate the estimated parameters in deterministic models because the heterogeneity of the subsurface is very hard to evaluate accurately for the use in deterministic models. Due to the groundwater flow problems, attributes like water level and salinity are collected at a few number of sites whereas values at the un-sampled sites are needed to further its analysis. As a conclusion, geostatistical techniques such as kriging or co-kriging can be applied to predict the values of attributes at un-sampled sites (Ma *et al.*, 1999).

There are many different applications of geostatistics ranging from the classical fields of mining and geology to soil science, hydrology, meteorology, environmental sciences, agriculture, and also structural engineering. As time goes, the advanced built of

computation facilities and the various kind of geostatistical software has making the spatial analysis of environmental popular (Nas and Berkday, 2010).

2.4.2 Kriging

In reality, there is no perfect or complete data collection at every single points for the scope area because we cannot avoid the actual constraints. Therefore, interpolation is a fundamental and essential method to do analysis, graphing and comprehension of 2 dimensional data. For the word "Kriging", it means the optimal prognostication. Kriging method will predicts unknown values from the data obtained at respective places. This method presented by semivariogram to express the spatial variation and has an advantage on minimizes the error of predicted values reckons by the spatial distribution of the predicted values (Lang, 2014).

On the other hand, Kriging method are also can be known as the best linear unbiased estimator since it will produce a result with minimum or even zero error. It has an objective that is to minimize the error variance where moving average or inverse distance weighting (IDW) can be calculated accurately in an effective way. For example, Kriging will creates weights encounter the measured values so that unmeasured locations can be determined their values. Kriging will weights for the surrounding of the measured points in a more sophisticated way than that of IDW because IDW only apply a simple algorithm based on distance while Kriging weights come from a semivariogram that was developed by viewing the spatial structure of the data (Al-Mashagbah *et al.*, 2012).

Actually, there are some spatial interpolation methods for spatial distribution of water quality parameters and they are IDW, Radial Basis, Local Polynomial, and Kriging. Kriging works the best because it can get extra information with the usage of random function. The flexibility of Kriging depends on the input parameters and it also does autocorrelation and errors of the prediction. Here are some types of Kriging for example Simple kriging, Universal Kriging, Block Kriging, Ordinary Kriging, Co-kriging and Disjunctive Kriging (BenthungoMurry, 2013).

Interpolation steps can be simple mathematical models like inverse distance weighting, trend surface analysis, Thiessen polygon and so on. For the more complex models of geostatistical methods they will be Kriging and thin plate splines. Kriging may simplify both the statistical and mathematical properties of the samples. It gives value to the spatial autocorrelation among the sample points and also together in the spatial configuration of the samples around the forecast location. Kriging is flexible and allow for the calculation of spatial autocorrelation for the data due to the use of statistical models.

The basic assumption in Kriging is about the data comes from a stationary random process and some formulae require that the data must be normally distributed. Furthermore, Kriging is divided into two different tasks that are quantifying the spatial structure of the data and producing a predicted surface model. Thus, the prediction of an unknown value for a specific point is through Kriging where they will use the best fitted model from semivariogram according to different types of model. Among all the different forms of Kriging, Ordinary Kriging has been used widely because it is known as a reliable estimation method (Nas, 2009).

Kriging method is founded and named in the honor of Dr. Kriging who was a noted South African mining geologist. With this invention, he used semivariogram to represent the estimates from a specified number of adjacent data with considering the interdependence. This application also have arisen regarding the study of spatial distributions soil water and salt in field, the interpolation to river spatial database, the spatial variance pattern of chemical substance circulation in swamp, the distribution of contaminant concentrations, and stream flow estimation. In addition, the average Kriging standard deviation use to estimate the error can be used as a measure of network effectiveness. For an optimal monitoring network, the standard deviation of error will be always the minimum. To determine the network density based on the Kriging method, there are two steps to be followed that are simulation and optimization. The benefit of the Kriging - based approach is that we can design the network as a test first without affecting the measurement of the estimation because the variance of estimation error is independent of actual measurements. However, Kriging does not consider on the physical information of

the wells like depth and also the coordinates of the wells. They need to be combined by using hydrogeological analysis (Feng-guang *et al.*, 2008).

A kriging needs an understanding of the principles of spatial autocorrelation and it is applied when the random data is irregular where simple methods of interpolation cannot be used. Basically, the spatial structure of stochastic dependence between results at different tried inputs is represented by covariance, semivariogram or the standardized measure of the correlation coefficient.

One of the Kriging method called Ordinary kriging (OK) provides the optimal estimated under the assumption where the process is a second-order stationary and is normally distributed. OK is the weighted linear combination of the observation with the white noise process. Therefore the optimal estimator will be established by reducing the mean squared prediction error. The collected values are used priory to predict the unknown parameters through this process and also to calculate empirical semivariogram. These collected values, parameters and semivariogram were used to create the best linear unbiased predictor of the unknown point (Ryu *et al.*, 2002).

All kriging estimates are but variants of the basic linear regression estimator Z^*u defined as:

$$Z^*(u) - m(u) = \sum_{\alpha=1}^{n(u)} \lambda_{\alpha} [Z(u_{\alpha}) - m(u_{\alpha})] \quad (2.1)$$

with

u, u_{α} : location vectors for estimation point and one of the neighbouring data points, indexed by α .

$n(u)$: number of data points in local neighbourhood used for estimation of $Z^*(u)$.

$m(u), m(u_{\alpha})$: expected values (means) of $Z(u)$ and $Z(u_{\alpha})$.

λ_α : kriging weight assigned to datum $Z(u_\alpha)$ for estimation location u ; same datum will receive different weight for different estimation location.

$Z(u)$ is treated as a random field with a trend component, $m(u)$, and a residual component, $R(u) = Z(u) - m(u)$. Kriging estimates residual at u as weighted sum of residuals at surrounding data points. Kriging weights, λ_α , is derived from covariance function or semivariogram, which should characterize residual component. The distinction between trend and residual somewhat arbitrary; varies with scale.

2.4.2.1 Simple Kriging

Simple Kriging (SK) supposes that the randomized spatial function is in static and the mean is constant over area of interest. However, this assumption is not right. Besides that, all the collected points are used for the calculation of each output pixel value in SK.

$$Z * SK(u) = m + \sum_{\alpha=1}^{n(u)} \lambda_\alpha SK(u) [Z(u_\alpha) - m] \quad (2.2)$$

with

u, u_α : location vectors for estimation point and one of the neighbouring data points, indexed by α .

$n(u)$: number of data points in local neighbourhood used for estimation of $Z^*_{SK}(u)$.

m : expected values (means) of $Z_{SK}(u)$ and $Z(u_\alpha)$.

λ_α^{SK} : kriging weight assigned to datum $Z(u_\alpha)$ for estimation location u ; same datum will receive different weight for different estimation location.

2.4.2.2 Ordinary Kriging

Ordinary Kriging (OK), the randomized spatial function is non-stationary and the mean varies per the area of interest. OK amounts to estimate again the mean at every new location. In OK, you can affect the number of points that should be taken into consideration

for the calculation of an output pixel value by specifying a limiting distance and a minimum and maximum number of points. Then, only the points that fall within the limiting distance to an output pixel will be used in the calculation for that output pixel value.

$$Z * OK(u) = \sum_{\alpha=1}^{n(u)} \lambda_{\alpha} OK(u) Z(u_{\alpha}) \quad \text{with} \quad \sum_{\alpha=1}^{n(u)} \lambda_{\alpha} OK(u) = 1 \quad \text{Eqn 2.3}$$

with

u, u_{α} : location vectors for estimation point and one of the neighbouring data points, indexed by α .

$n(u)$: number of data points in local neighbourhood used for estimation of $Z^*_{OK}(u)$.

m : expected values (means) of $Z_{OK}(u)$ and $Z(u_{\alpha})$.

λ_{α}^{OK} : kriging weight assigned to datum $Z(u_{\alpha})$ for estimation location u ; same datum will receive different weight for different estimation location.

2.4.2.3 Anisotropic Kriging

Anisotropic Kriging (AK) is a mutation of OK. AK involves the influence of direction dependency.

2.4.2.4 Universal Kriging

Universal Kriging (UK) is another mutation of the Ordinary Kriging operation where it is a Kriging referring to a local trend. The local trend or drift is a continuous and slowly changing trend surface which the changes to be interpolated is superimposed. The prediction of a 'fixed' mean in OK is replaced by a prior trend model which is combined into the predictions.

2.4.2.5 Co-Kriging

Co-Kriging (CK) is a multivariate extension of the OK method. For example, one parameter which is too sparsely sampled to carry out an accurate interpolation, is highly correlated with another parameter of which enough samples are available to do Kriging. Based on the well sampled data set Kriging is carried out (net, 2014).

There are some of the advantages of Kriging as stated below:

- Helps to compensate for the effects of data clustering, assigning individual points within a cluster less weight than isolated data points (or, treating clusters more like single points)
- Gives predict of estimation error (kriging variance), along with an estimate of the variable, Z , itself (but error map is basically a scaled version of a map of distance to the nearest data point, so not that unique)
- Availability of estimation error provides a basis for stochastic simulation of possible realizations of $Z(u)$ (Bohling, 2005).

2.4.3 Semivariogram models

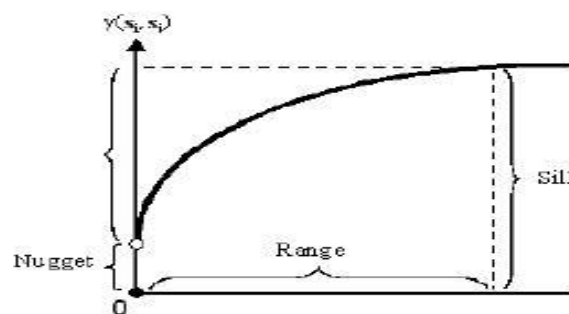


Figure 2.1: Semivariogram model

Sources: (Esri, 2015)

Stated by Nas (2009), a semivariogram plot, semi variance versus average lags, is acquired by calculating values of the semivariogram at different lags whereby these value points are then fitted with a theoretical model: spherical, exponential, circular, wave, Gaussian and many more. The models will deliver information about the spatial structure and also the input parameters for the Kriging interpolation like nugget, sill and range. For every semivariogram model plotted, we have to test by input the estimated parameter values to get the best fitted graph accordingly. Cross validation is used to evaluate its prediction performances. In addition, cross validation permits the judgement of which is the best model which provide the best predictions among others. As a model which gives accurate estimations, its standardized mean error should be close to zero as well as the root mean square error and the average standard error should be in the minimum state. By doing this, we can do a comparison between the models to obtain the best one. Lastly, the root-mean square standardized error will approximately to one for an accurate estimation.

2.4.3.1 The effect of sill

Sill represents the semivariogram value when the distance approaches infinity. The values of rescaling semivariogram will not affect the estimation and also the weight. However, the variance of estimation error will be influenced by the same factor if the semivariogram values was being rescaled. With the same number of observation wells, the average standard deviation is high in value for large sill. Therefore, for a given maximum tolerable average standard deviation, more observation wells are required for the case with large sill values.

2.4.3.2 Nugget effect

The nugget effect is caused by a little variations, or sometimes it can be just by measurement errors. It causes a crack at the origin. The nugget effect does affects the Kriging weights and the variance of the estimation error. To the nugget effect, the Kriging weights become similar and the variance of estimation error will increase. The nugget effect does not only increase the average standard deviation, it also changes the shape of the

network density graph. If there is no nugget effect, the average standard deviation generally decreases with the increase of the number of observation wells. However, with a remarkable nugget effect, the average standard deviation does not significantly decrease beyond a relatively small number of observation wells.

2.4.3.3 *The effectiveness range*

The effectiveness range is the distance beyond which the semivariogram value remains essentially constant. The range is a measure of correlation scale indicating the spatial correlation of regionalized variables. The larger the range is, the stronger the spatial correlation is. The changes of range will have the effects both on the Kriging estimate and the variance of the estimation error. With the same number of observation wells, the average standard deviation decreases with the increase of the range. Therefore, to achieve a given tolerable average standard deviation, more observation wells are needed for systems with a small range.

If additional validated points can be rendered, the maximum absolute error, the average absolute error and the root mean squared error of these points can be determined to check for the model accuracy. The values of n , y_i and \hat{y}_i indicate the number of the untried points used to test, the real values from input and the predicted value from the kriging model (Ryu et al., 2002).

The main problem of Kriging is to predict the law of variable changed with space and then to estimate the unknown value based on the collected samples. This law is called as semivariogram. Semivariogram is used to represent the spatial structure of any variable. The semivariogram of samples, which is also called experimental variogram, can be calculated by the following formula:

$$\gamma^*(h) = \frac{1}{2N_h} \sum_{i=1}^{N_h} [Z(xi+h) - Z(xi)]^2 \quad (2.4)$$

where N_h denotes the number of pairs separated by vector h , vector h denotes lag distance, x_i denotes the starting location and $x_i + h$ denotes the ending location. If γ is the only dependent on the length of lag distance but not its direction, γ is an isotropic as well as the variable Z . For the sake of simplicity, we only consider isotropy of Kriging.

Normally, observe the distribution of semivariogram and pick a reasonable variogram model. After that, apply least square method to fit the semivariogram in accordance with the principle of minimum variance estimate, which produce a fitting curve called empirical variogram. Semivariogram model comprises a basic model or a linear combination of several basic models. The common theoretical model of semivariogram basically includes linear model, spherical model, exponential model, Gaussian model, power model and so on (Huang *et al.*, 2012).

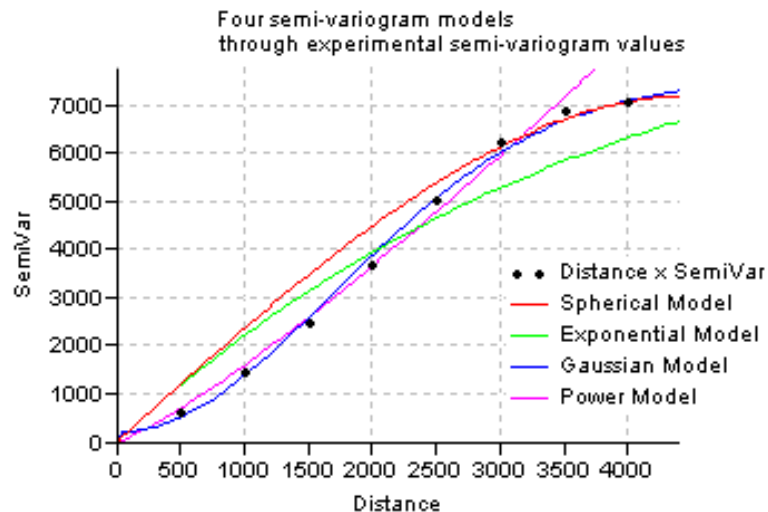


Figure 2.2: Different types of semivariogram models

Sources: (Analyst.net, 2014)

2.5 THE IMPORTANCE OF GEOGRAPHICAL INFORMATION SYSTEM

Nowadays, GIS technologies has been widely applied to diverse fields for example education, business, natural resources, mapping and charting, geospatial intelligence, government, tourism, health services, public safety transportation and so on. The introducing of GIS is to connive professionals and experts in order to interpret various types of geospatial data and handle complex situations. No matter any fields, GIS plays an important role to help people capture, store, manipulate, analyse, manage, and present all types of spatial data with different formats (Supergeo, 2014).

In the field of water resources, GIS is so beneficial to show all the defined data within a spatial case like the recharge of groundwater, rain precipitation, and groundwater locations can be seen in a generated map. Furthermore, all the relationships or connections between these criteria can also be simply interpolated because GIS is virtually a database where all these data can be combined in so many different ways. Many analysis can be done based on one model map by having a scope of area and information regarding their parameters (Martinez, 2014).

The objectives of GIS is to store attribute and spatial data as different layers. After that, these layers will be interpolated to a result as output data. Using a GIS in the modelling of small watersheds is not a new concept. The hydrological models generated can be very useful for us to do a prediction of hydrological processes and also the watershed quality. Not only that, this system can supply essential input data for a hydrological model that is in both space and time.

In fact, GIS should apply as a pre or post-processor for hydrological modelling because it lacks of time to deal with different data structures, lineage and product quality information. Therefore, it should be employed as a protracted spatial database which can be used repeatedly. Brendon Wolff-Piggott, who complimented GIS is the best system for its map capabilities and the evaluation provided on discovering the configuration errors (Pretoria, 2014).

Both the groundwater quality analysis and geographic information system (GIS) based mapping are major components of a groundwater planning strategy. Analysis based on hydro chemical studies can help us to predict the potential contaminated zones and show a suitability map of water for drinking, irrigation, or other purposes. GIS can also be used to determine the groundwater pollution spots and to get any reliable information about the recent groundwater quality parameters which may be essential for the effective and efficient fulfillment of water management programs. In India, there are several groundwater related studies have been conducted for example the determination of potential sites for groundwater evaluation and groundwater quality mapping by using GIS-based software (Adhikary *et al.*, 2012).

2.6 INTEGRATED LAND AND WATER INFORMATION SYSTEM

Integrated Land and Water Information System (ILWIS) is a GIS / Remote sensing software for both vector and raster processing. ILWIS features include digitizing, editing, analysis and display of data for quality maps. Besides that, the developer and distributor of ILWIS were by International Institute for Geo-Information Science and Earth Observation (ITC Enschede) in the Netherlands and this software was basically only for its students and researchers. Fortunately, ILWIS has been distributed under the terms of the General Public License (GNU) since the 1st of July 2007. Therefore, it is a free download, licensed software for public now. Furthermore, it is one of the most user-friendly integrated vector and raster software programs because of its downloadable modules available on the website like the powerful raster analysis modules, a high-precision and flexible vector and point digitizing module, a variety of very practical tools and also a great variety of user guides and training modules. The current version of the software is ILWIS 3.4.0 which is only available natively on Microsoft Windows.

ILWIS has a lot of functions and these are the list of them as below:

- Integrated raster and vector design
- Import and export of widely-used data formats

- On-screen and tablet digitizing
- Comprehensive set of image processing tools
- Orthophoto, image Geo-referencing, transformation and mosaicking
- Advanced modelling and spatial analysis
- 3D visualization with interactive editing for optimal view finding
- Rich projection and coordinate system library
- Geo-statistical analyses, with kriging and co-kriging for improved interpolation (Westen, 2014)

2.7 GAPS IN THE LITERATURE

To date, there are only few research on the selection of the best semivariogram models in groundwater quality mapping. This is the best time to investigate the most suitable models and the techniques of simple kriging method for point interpolation with different semivariogram models.

Furthermore, there are only a few studies which deal with the application of GIS on groundwater quality assessment. Besides that, GIS in Malaysia is still not that integrated and expertly used currently. By doing a laboratory test of the groundwater quality is quite slow and the scope of the area is limited. By GIS techniques, result can be obtained in a more economical and effective way.

Therefore, this opportunity was given to contribute to Malaysia and boost up the application of GIS and rasterize techniques in conjunction with providing extra information to the Minerals & Geoscience Department Malaysia (JMG) in the future.

2.8 CONCLUSION

In this chapter, groundwater quality parameters which consists of the two main parameters such as pH values, and Sulphate (SO_4) were discussed. In addition, the spatial pattern which consists of geostatistics, kriging and semivariogram model also being explored. Furthermore, the importance of GIS for groundwater quality modelling and mapping for analysis purpose were studied. Last but not least, Integrated Land and Water Information System (ILWIS) was chosen as my GIS software. This study will contribute to GIS user and also JMG Malaysia so that it can run through spatial analysis with further advanced knowledge and information.

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

This chapter will discuss about a brief overview of the data analysis and procedures of my research projects. There were a few steps should be fulfilled to ensure that the effectiveness and appropriateness of defining and justifying this study. Among them are as below:

- Collect data of minimum 200 wells coordinates for the study area.
- Obtain groundwater quality parameter data for each of the wells like pH value and SO₄ for the year of 2012.
- Install a GIS and RS software, ILWIS 3.4 into the computer for modelling and mapping purpose.
- Develop of spatial database and spatial analysis by using GIS software.
- Determine and evaluate the model data of study area for future prospect.

3.1 RESEARCH DESIGN- OBSERVATION

A research design is a systematic plan to study a scientific problem. Correlational (Observational study) has been chosen as the type of design because it draws a conclusion by comparing subjects against a control group.

This study will be accomplished by completing the tasks given in the detailed of the diagram of research design as shown in Figure 3.1.

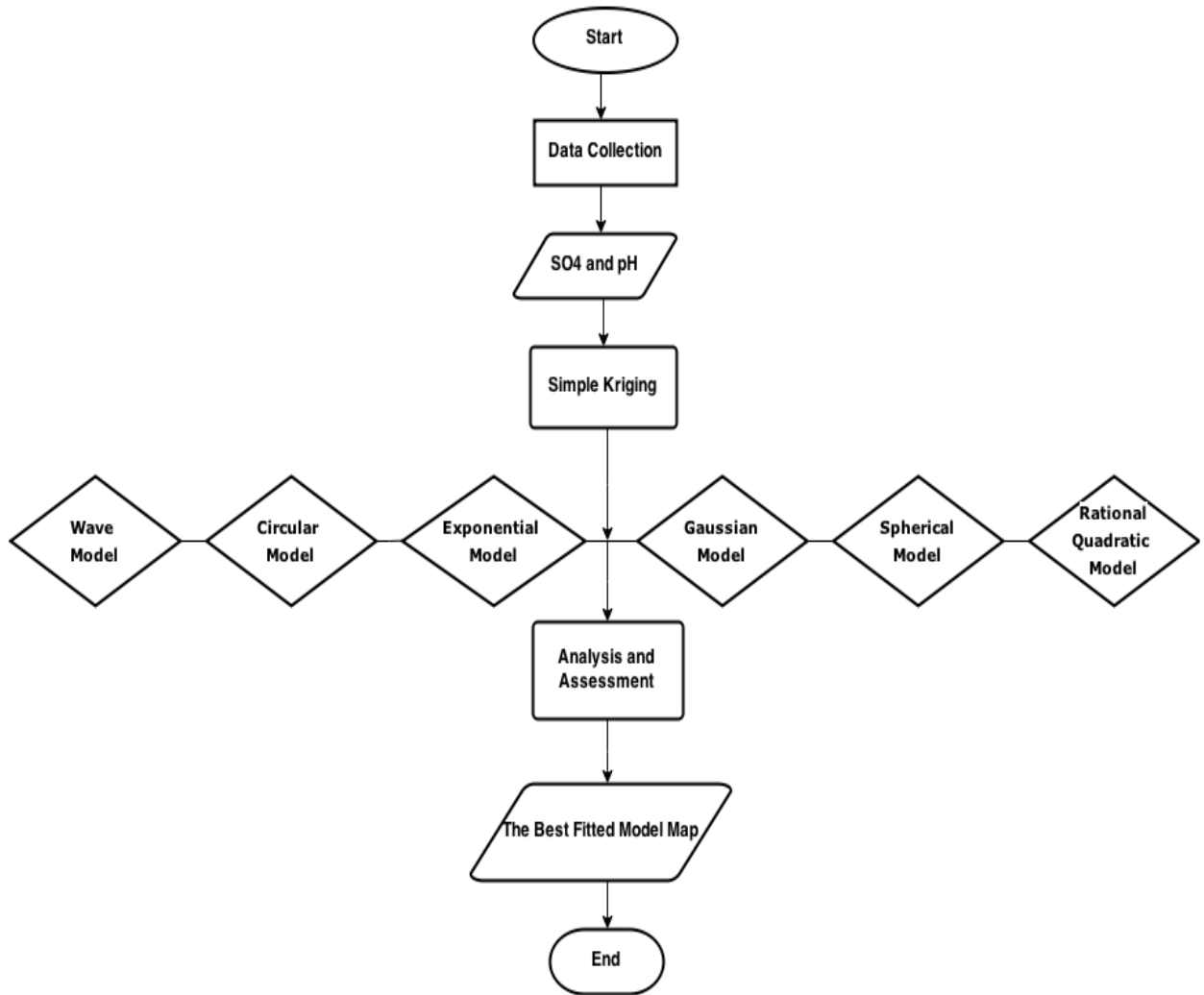


Figure 3.1: Flow diagram of research design

3.2 DATA COLLECTION

Data was acquired from main sources. Firstly the survey data like the wells coordinates of the study area and the groundwater quality parameters including pH, and

SO₄ for the year of 2012 needs to be collected for the map modelling. The data can be in hard copy or soft copy. The details of the data are elaborated below.

3.3 SURVEY

Survey works consist of two matters that are minimum 200 of wells coordinate located at Khorasan Razavi-Iran and also the water quality parameters like pH value and SO₄ for each of the wells collected for the year of 2012. This data can be obtained from my supervisor since he got those data. The data got was in soft copy which is in shape file from ArcGIS.

3.4 PRE-PROCESSING

In this Pre-Processing, the spatial data for example the wells quality shape file was already in GIS format. If the file which is not supported by the software, convert them into the file format which can be applied in the software. If got a hard copy of data, import these data from excel file. Thus, you require keyboard entry and importing to make sure that all these data are supported and used in ILWIS.

3.4.1 Keyboard Entry

It requires key in the data manually into the computer. Attribute data are usually entered by keyboard. Keyboard entry also will be used during the manual digitizing to key in the attribute data. However, this is usually more efficiently handled as a separate operation. For example the groundwater quality parameters must use this method to import all the information into the software so that it can be generated and used for further analysis. This is the creation of a set of database.

3.4.2 *Manual Digitizing*

This is the most widely used methods for encoding spatial data from maps. The map needs to be imported to a digitizing tablet first and then use a hand held device known as a puck, or a cursor to trace each of the require map features like the location of wells and some of the features around the wells. The position of the puck is accurately measured by the device to generate the coordinate data. It has a digitizing surfaces range, which is about 12 inches x 12 inches of a digitizing tablet with 36 inches x 48 inches of a digitizing table and others. The digitizing table will encode the position of the pointing device electronically with a precision of a fraction of a millimeter.

For the most common digitizer, it uses a fine wire mesh grid embedded in the table. The cursor normally has sixteen or more buttons for the data entry and to encode attribute data. This digitizing operation consumes a computing power and therefore it can be done without using the full GIS. A smaller, less expensive computer can be used to control the digitizing process and store the data. The data can later be transferred to the GIS for processing. The problem with this is having enough software for all the computers. The efficiency of digitizing depends on the quality of the digitizing software and the skill of the operator.

The process of tracing lines is time-consuming and error prone. The software can provide aids that substantially reduce the effort of detecting and correcting errors. Attribute information may be entered during the digitizing process, but usually only as an identification number. The attribute information referenced to the same ID number is entered separately. A commonly used quality check is to produce a verification plot of the digitized data that is visually compared with the map from which the data were originally digitized.

3.4.3 *Automatic Digitizing (Scanning)*

Scanning provides a faster means of data entry compared to manual digitizing. By scanning, a digital image of the map is produced by moving an electronic detector across the surface of the map.

There are two types of scanner designs:

- Flat-bed scanner: On a flat-bed scanner the map is placed on a flat scanning stage and the detectors move across the map in both the X and the Y directions (similar to copy machine).
- Drum scanner: On a drum scanner, the map is mounted on a cylindrical drum which rotates while the detector moves horizontally across the map. The sensor motion provides movement in the X direction while the drum rotation provides movement in the Y direction.

The output from the scanner is a digital image. Usually the image is black and white but scanners can record the colour by scanning the same document three times using red, green and blue filters.

For the scanned map, it can be saved as bmp or tif file format to be opened in ILWIS. Go to the (Open) icon and then go to the folder where the map file situated at. After that, go to (File) and click on the (Import) and then (Map). It will appear an Import window. Now go to the (Import Format) and choose the scanned map format and click (Ok). This time the scanned map has been successfully imported into the software to further analysis.

3.4.4 *Importing*

There are many companies and organizations on the market that provide or sell digital data files often in a format that can be read directly into a GIS. These digital data sets are priced at a fraction of the cost of digitizing existing maps. Over the next decade, the

increased availability of data should reduce the current high cost and lengthy production times needed to develop digital geographic databases.

Step 1:

For the data, copy the files into Local Disk C driver to open it. After that, import the data by clicking File → Import → Map → Import Format (.SHP) → Wellsquality.shp → OK. Now the file has been imported into ILWIS.

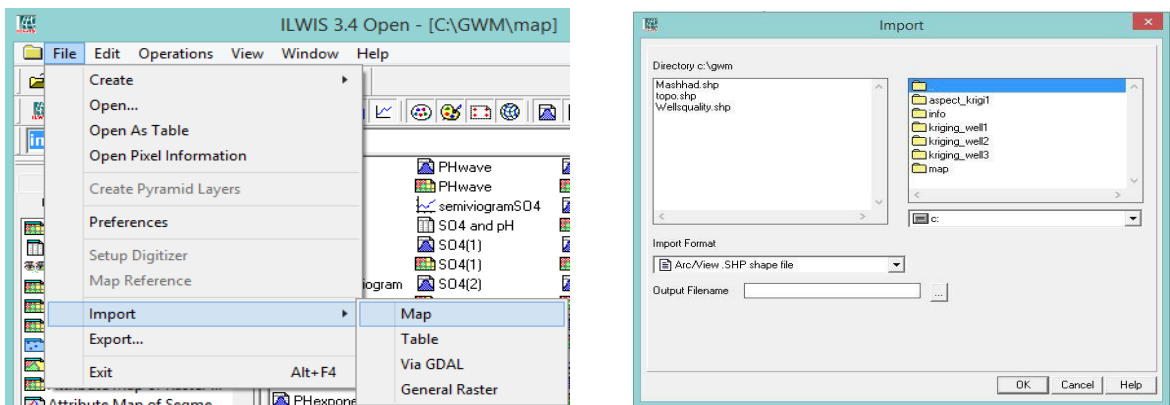


Figure 3.2: Import the shape files into ILWIS 3.4

Step 2:

At last, create a new coordinate system for the project. Here is the step of the new coordinate system. Operation-List → New Coordinate System → Coordinate System Name (UMP) → Description (UMP) → CoordSystem Boundary Only → OK. Change every Point Map into UMP coordinates system.

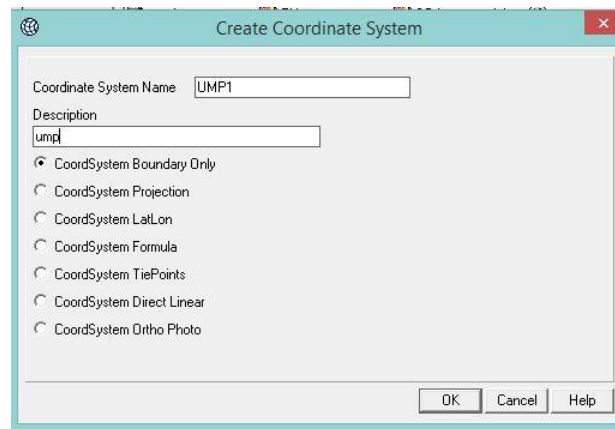


Figure 3.3: Create new coordinate system for research area

Step 3:

After Import, create a SO_4 and a pH map by using the Attribute Map of Point Map. Firstly to create a SO_4 Point Map, Operation-List \rightarrow Attribute Map of Point Map \rightarrow Point Map (wellsquality) \rightarrow Table (wellsquality) \rightarrow Attribute (SO_4) \rightarrow Output Point Map (SO_4) \rightarrow Show. Well for the PH Point Map, Operation-List \rightarrow Attribute Map of Point Map \rightarrow Point Map (wellsquality) \rightarrow Table (wellsquality) \rightarrow Attribute (PH) \rightarrow Output Point Map (PH) \rightarrow Show. Now two separated Point Map for Point Interpolation Analysis were formed.

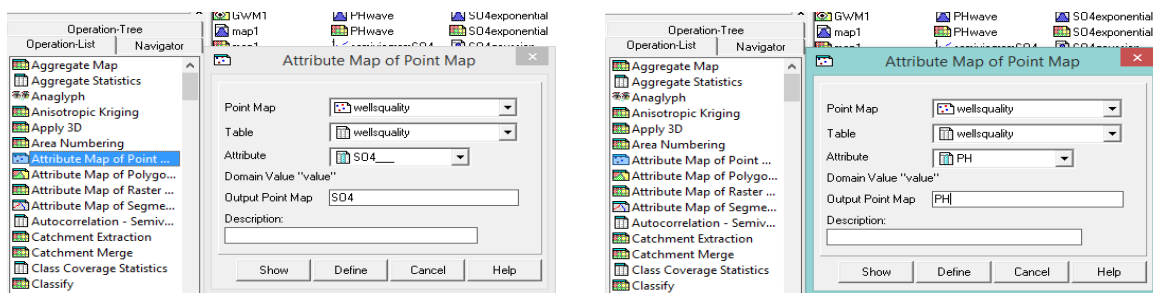


Figure 3.4: Create a quality point map of SO_4 and pH

3.5 GEODATABASE

A spatial database where a database is optimized to store and find out data that represents features defined in a geometric space. The discrete geographical features like points, lines and polygons can represent most of the spatial database. Some spatial databases handle more complex structures such as 3D objects, topological coverages, linear networks, and TINs. While typical databases are designed to manage various numeric and character types of data, additional functionality needs to be added to databases to process spatial data types efficiently. These are typically called geometry or feature. The Open Geospatial Consortium created the Simple Features specification and sets standards for adding spatial functionality to database systems.

The geodatabase offers you the ability to:

- Store a rich collection of spatial data in a centralized location.
- Apply sophisticated rules and relationships to the data.
- Define advanced geospatial relational models (e.g., topologies, networks).
- Maintain integrity of spatial data in a consistent, accurate database.
- Work within a multiuser access and editing environment.
- Integrate spatial data with other IT databases.
- Easily scale your storage solution.
- Support custom features and behavior.
- Leverage your spatial data to its full potential.

3.5.1 *Estimating Semivariogram Parameters*

Before doing kriging, we have to estimate the nugget, sill and range respectively to different types of semivariogram models. To plot semivariogram, data like semi variance and also average lag were needed. So a process called spatial correlation applied where the semi variance being calculated. The steps to do it was shown as follow.

Step 4:

SO₄ Point Map (right click) → Statistics → Spatial Correlation → Point Map (SO₄) → Omnidirectional → Lag spacing (m) (100) → Output Table (SO₄) → Show. We also have to do the same thing for PH Point Map. Continue the following steps as provided. PH Point Map (right click) → Statistics → Spatial Correlation → Point Map (PH) → Omnidirectional → Lag spacing (m) (100) → Output Table (PH) → Show.

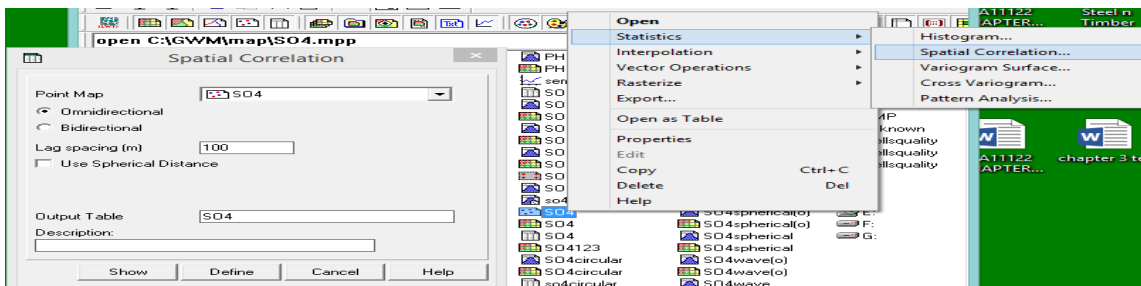


Figure 3.5: Calculate for the semi variance by spatial correlation

Step 5:

After creating a semi variance table for SO₄ and PH, proceed to plot the semivariogram for SO₄ and also PH as follows. PH dependent table → File → Create → Graph → Table (PH) → X-Axis (AvgLag) → Y-Axis (SemiVar) → OK.

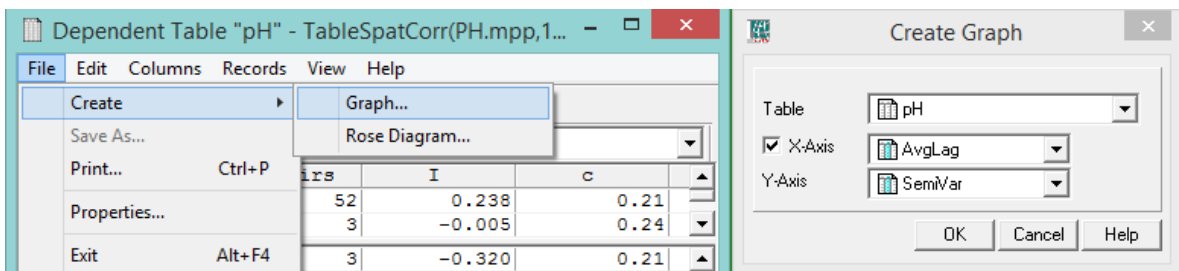


Figure 3.6: Plot semivariogram graph

Step 6:

Now is the time to plot the best fitted semivariogram model from the semivariogram. The steps were as follows. SO₄.grf → Edit → Add Graph → Semivariogram Model → Semivariogram (Spherical Model) → Nugget (estimated value) → Sill (estimated value) → Range (estimated value) → OK. Do for every different model together with the best estimated value to produce the best fitted line on the graph for pH and SO₄.

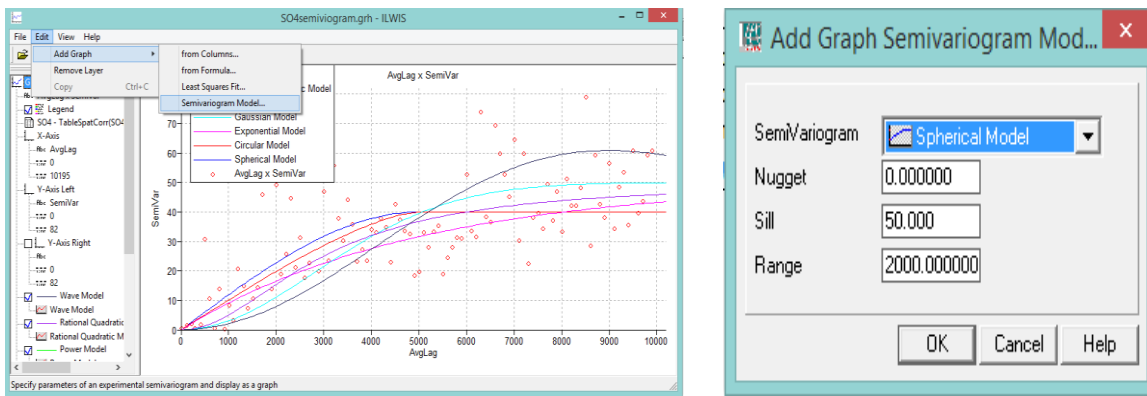


Figure 3.7: Draw semivariogram with different models

Record down all the different values of Nugget, Sill and Range for all the semivariogram models to proceed with the point interpolation.

3.5.2 Point Interpolation

For kriging, after recorded down all the estimated data of semivariogram parameters, proceed to the raster map or quality map generation. Here is the step by step procedure to create quality map.

Step 7:

SO₄ Point Map (right click) → Interpolation → Kriging → Point Map (SO₄) → SemiVarioqram (choose any one) → Nugget (estimated value) → Sill (estimated value) → Range (estimated value) → Method (Simple Kriging) → Remove Duplicate → Average → Tolerance (m) (0.1) → Output Raster Map (SO₄...) → GeoReference (UMP) → Show.

This is the only quality map of a semivariogram model for Simple Kriging on SO₄. For the rest, the steps are just the same. Create all together 6 of the SO₄ quality map by SK and also 6 of pH quality maps by SK accordingly. There are 12 of quality maps as the result of this research.

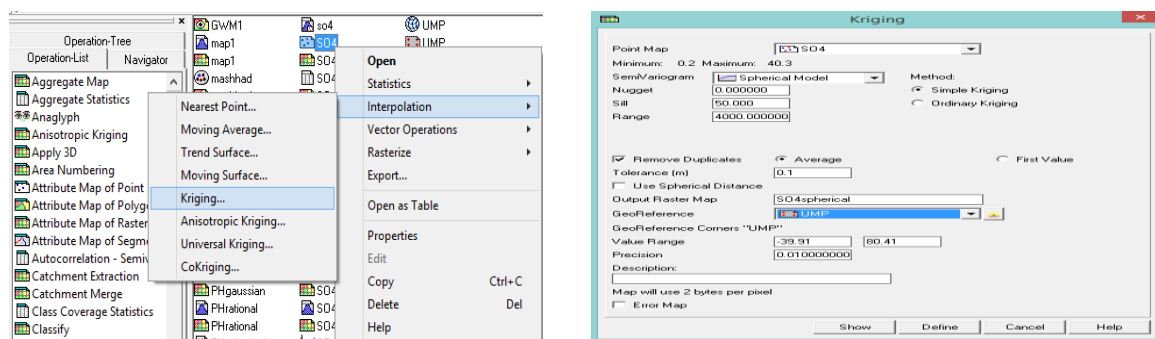


Figure 3.8: Interpolate by simple kriging

Next, after generated all the quality maps, show out the accuracy of the estimated value with the actual value. Here is the process to show out the table of value from the point map of actual one and the estimated one. Before that, rasterize the point map into a raster map as shown below.

Step 8:

SO₄ (right click) → Rasterize → Point to Raster → Point Map (SO₄) → Output Raster Map (any name) → GeoReference (UMP) → Show.

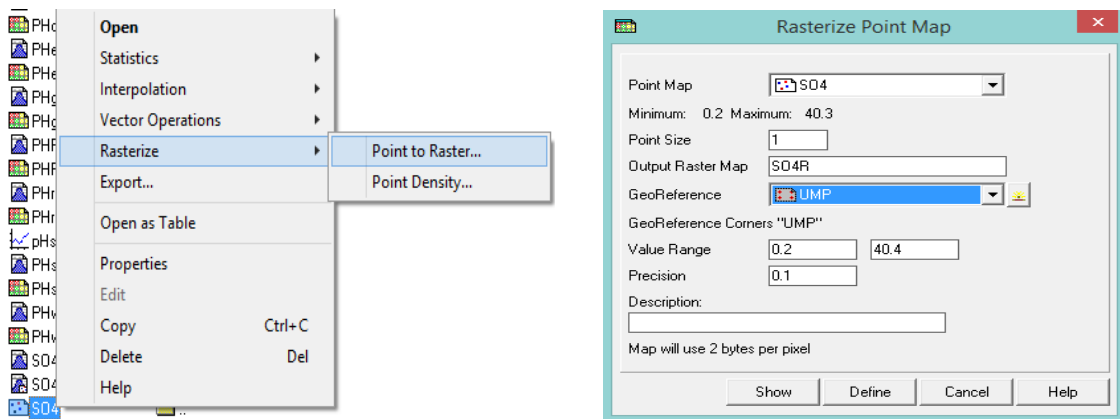


Figure 3.9: Rasterize the point map into raster map

The below is the software code information to pick out the data value of the estimated raster map according to the wells coordinate.

[filename for new map]=iff(isundef[filename of rasterize actual point map] ,?,[filename of estimated raster map])

Example:

map1=iff(isundef(so4r),?,so4circular)

To do that, firstly type the comment into the comment box as shown and generate a raster map with only specific coordinates.

Step 9:

map1=iff(isundef(so4r),?,so4circular) → Show → Open.

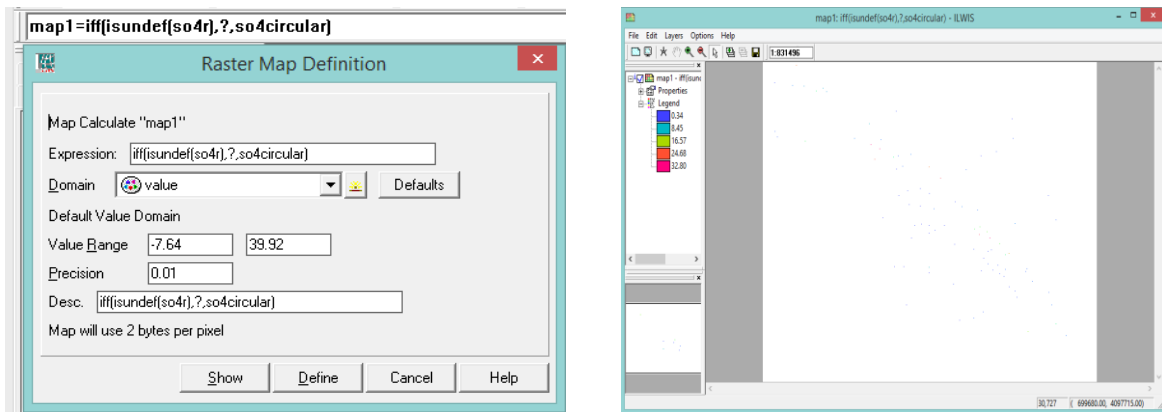
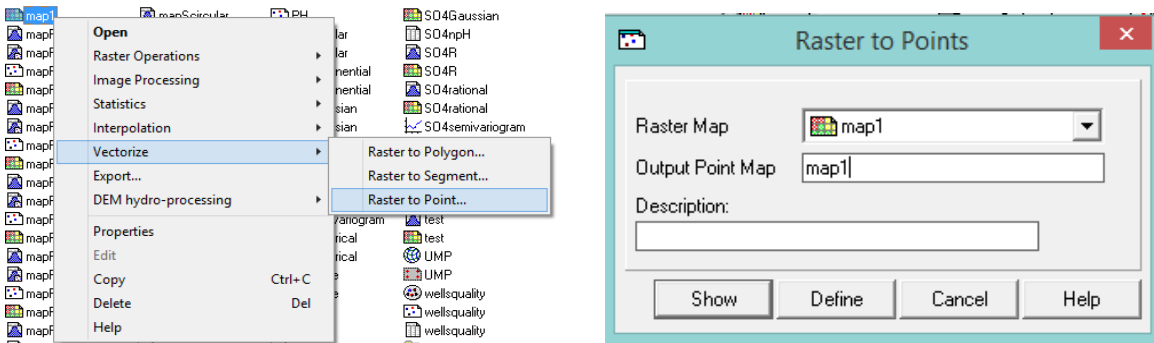


Figure 3.10: Create a raster map according to coordinate points

To create point map as the actual point map, vectorize the new map generated into a new point map as shown following steps.

Step 10:

map1 (right click) → Vectorize → Raster to Points → Raster Map (map1) → Output Point Map (map1) → Show → Open.



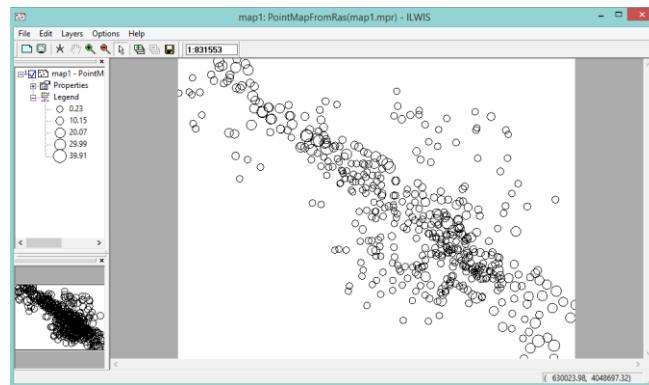


Figure 3.11: Vectorize the new raster map into point map

These steps are repeated for all others quality maps from Step 9 to Step 10 to produce all the new point map.

The procedure above was the determination of the best fitted model for groundwater quality mapping. The next objective of the study is to look for the trend of accuracy depend on the lag distance of the point interpolation. Chose 50 points from the actual data with 472 points to undergo the process.

Step 11:

Here is the step to obtain the quality information from the best fitted raster map. First, open the best fitted raster map (SO₄ rational) → Layers → Add Layer → SO₄ → Ok.

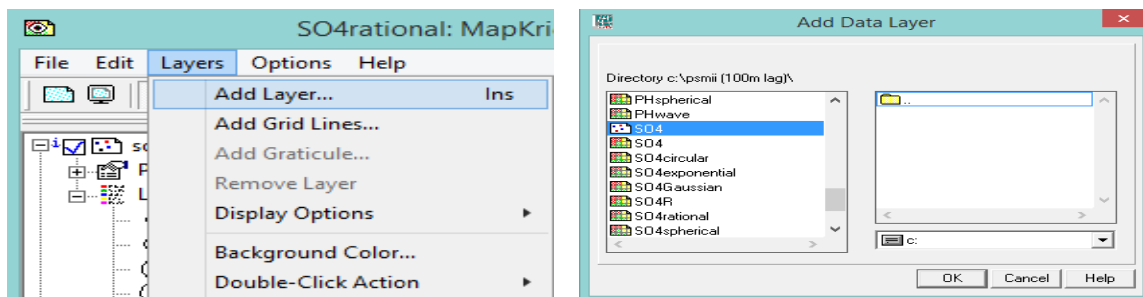



Figure 3.12: Add a layer of the SO₄ point map into the raster map

Step 12:

Secondly, zoom in any area to get a quality value from. Click on the icon Zoom In  above the map.

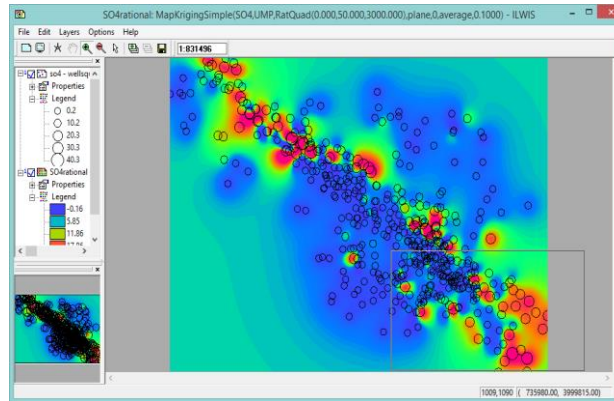


Figure 3.13: Zoom in the map area

Step 13:

After zooming into the area, now select File (Open Pixel Information to open the table of pixel information – ILWIS to collect the data of SO₄ and also SO₄ rational by pointing on any points.

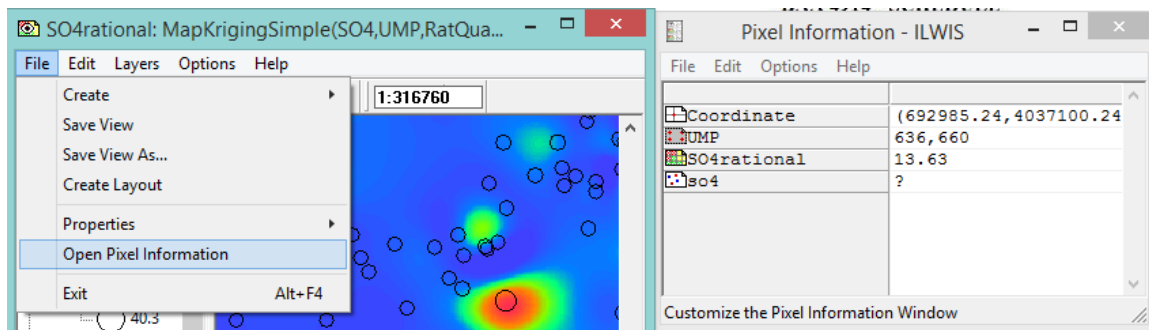



Figure 3.14: Open the pixel information table

Step 14:

To get the information among lag of 500m, 1000m, and 1500m from the actual point, select the icon measure distance  to record down the data value by measuring the distance from the points with 500m, 1000m, and 1500m so that the value can be shown in the pixel information. Do it for 50 points from the map.

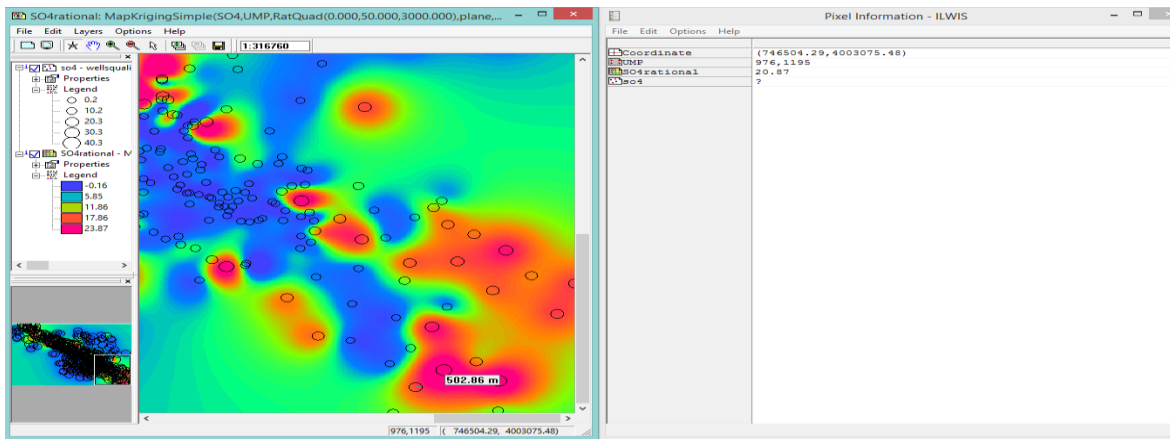


Figure 3.15: Measure for 500m, 1000m, and 1500m and obtain value from the pixel information

3.6 FINDINGS

After creating all the different quality raster maps and estimated point maps respectively, all the estimated value needed to compare with the actual value for SO₄ and pH so that we can choose the best semivariogram models to be used for interpolation depend at 100m lag and also to find out the trend of the accuracy changes versus the lag distance.

Firstly, right click the actual point map and the estimate point map and then select Open as Table to show out the table according to the coordinate respectively.

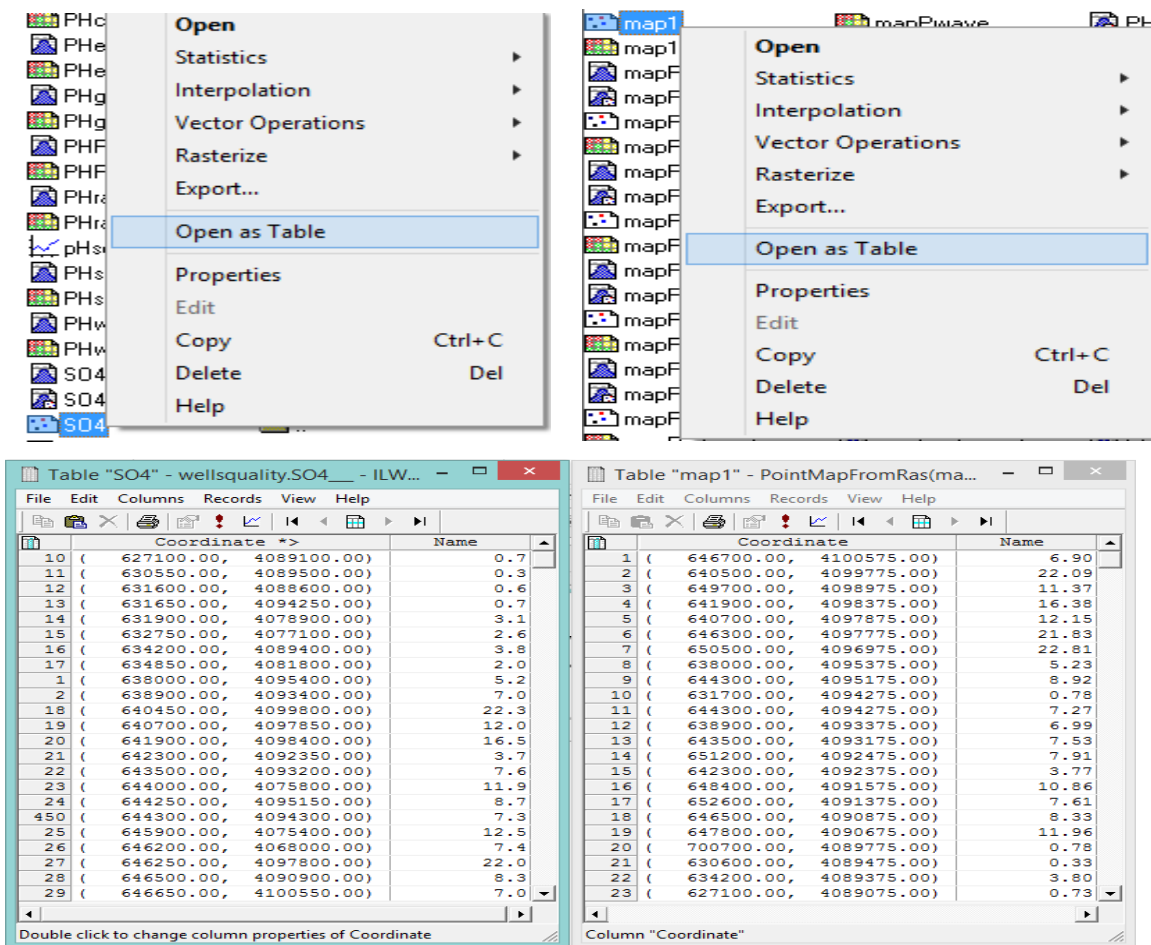


Figure 3.16: Open table for SO₄ point map and each of the new estimated point map

To make all the coordinate in order, select or highlight all the coordinates and then right click it and select Sort Ascending. After that, all the coordinates together with their value will be automatically arranged ascendingly. Copy the value of the column Name of the actual quality table and estimated quality table to make a comparison table in Microsoft Excel.

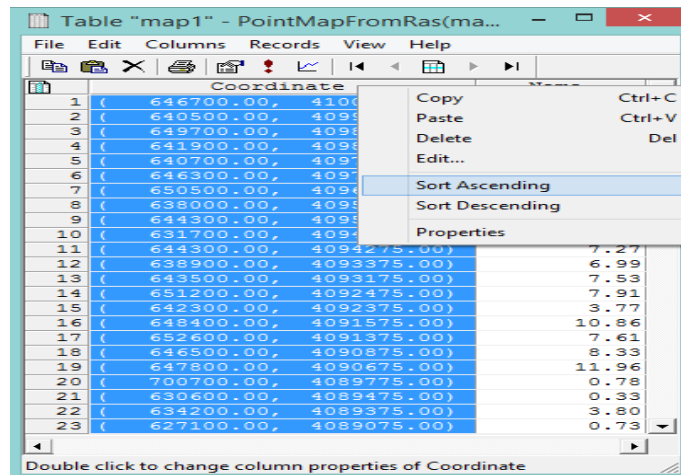


Figure 3.17: Sort the coordinate ascendingly for comparison

All the evaluation of the best fitted model for groundwater quality mapping and the trend of accuracy versus the lag distance will be determined by generating scatted chart to come out with the Coefficient of determination, R^2 . R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1 indicates that the regression line perfectly fits the data.

Secondly, the evaluation also done by using Nash–Sutcliffe model efficiency coefficient, E . Nash–Sutcliffe efficiencies can range from $-\infty$ to 1. An efficiency of 1 ($E = 1$) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency is to 1, the more accurate the model is.

In addition, the Root Mean Square Deviation (RMSD) or Root Mean Square Error (RMSE) was used too. It is a frequently used measure of the differences between values

predicted by a model or an estimator and the values actually observed. In GIS, the RMSD is one measure used to assess the accuracy of spatial analysis and remote sensing. RMSD is a good measure of accuracy.

As a result, the higher the R^2 value; the higher the E value; and the lower RMSD is denotes the best fitted model and the most accurate value to the actual one. For the trend of accuracy, the R^2 and E value may decrease and RMSD may get larger in value to indicate the larger the lag distance, the less accurate for the estimation to the actual value.

3.7 CONCLUSION

In this chapter, it briefs about the preparation of data collection and the storing of data or data encoding into digital format to create an establishment of a database. There are three stages which are the data collection, pre-processing and geodatabase procedures to be done so that the research objectives can be accepted.

CHAPTER 4

RESULTS AND DISCUSSION

In this study, all the SO₄ and pH raster map based on different semivariogram models have been generated by point interpolation, Simple Kriging. Before that, Figure 4.1 shown that the point map of the wells coordinates sample location and Figure 4.2 shown about the well coordinates of sample and their respective attribute water quality data for SO₄ and pH in this research.

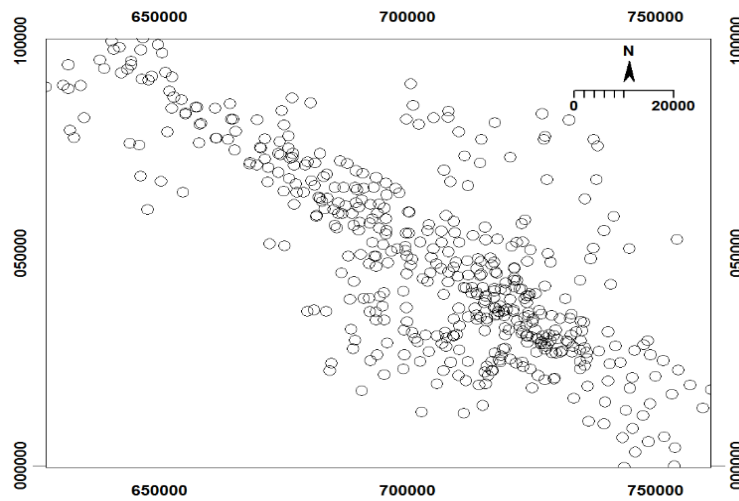


Figure 4.1: Point map of well samples at study area

	SO4	PH
1	5.2	8.2
2	7.0	8.4
3	0.3	7.9
4	8.5	8.1
5	0.8	8.2
6	9.9	8.3
7	6.0	7.7
8	0.7	7.4
9	2.7	7.3
10	0.7	8.0
11	0.3	8.2
12	0.6	8.2
13	0.7	8.3
14	3.1	7.9
15	2.1	8.2
16	2.6	7.8
17	3.8	7.9
18	2.0	7.9
19	6.1	7.8
20	12.9	8.2
21	16.5	8.3
22	3.7	8.1
Min	0.2	6.4
Max	40.3	8.8
Avg	6.1	7.8
Std	7.5	0.4
Sum	3073.3	3932.7

	Coordinate	Name
1	(638000.00, 4095400.00)	1
2	(638900.00, 4093400.00)	2
3	(647600.00, 4060200.00)	3
4	(661400.00, 4077000.00)	4
5	(677500.00, 4066200.00)	5
6	(679400.00, 4070700.00)	6
7	(695650.00, 4054450.00)	7
8	(701000.00, 4031200.00)	9
9	(720700.00, 4024900.00)	10
10	(627100.00, 4089100.00)	11
11	(630550.00, 4089500.00)	12
12	(631600.00, 4088600.00)	13
13	(631650.00, 4094250.00)	14
14	(631900.00, 4078900.00)	15
15	(632750.00, 4077100.00)	17
16	(634200.00, 4089400.00)	18
17	(634850.00, 4081800.00)	19
18	(640450.00, 4099800.00)	20
19	(640700.00, 4097850.00)	21
20	(641900.00, 4098400.00)	22
21	(642300.00, 4092350.00)	23
22	(643500.00, 4093200.00)	24
23	(644000.00, 4075800.00)	25

Figure 4.2: Attribute data of sample coordinates, SO₄ water quality and pH water quality

Here are all the results of SO₄ and pH maps as shown below after being a point interpolated by simple kriging:

SO₄ raster maps:

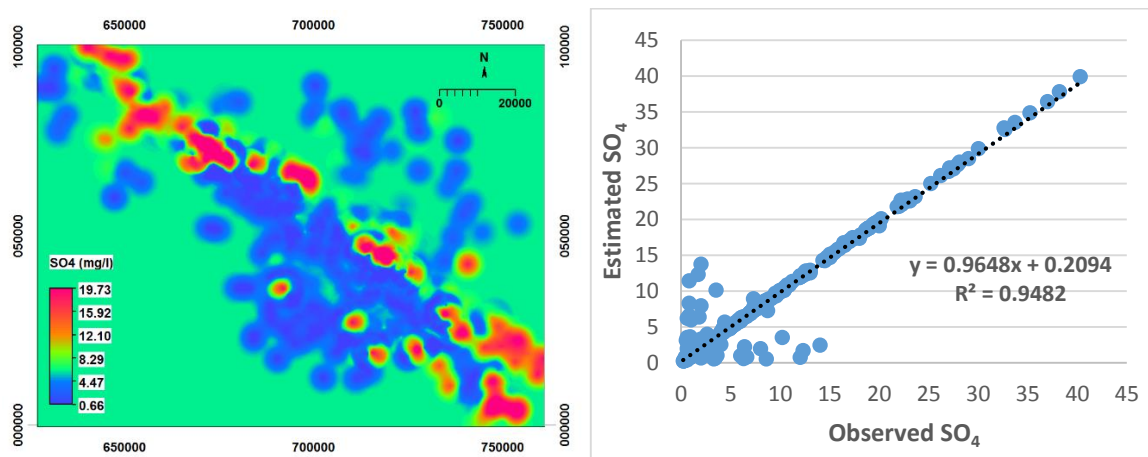


Figure 4.3: Spatial variation of SO₄ in the study area using Kriging (Circular Model, Nugget=0; Sill=40; Range=5000)

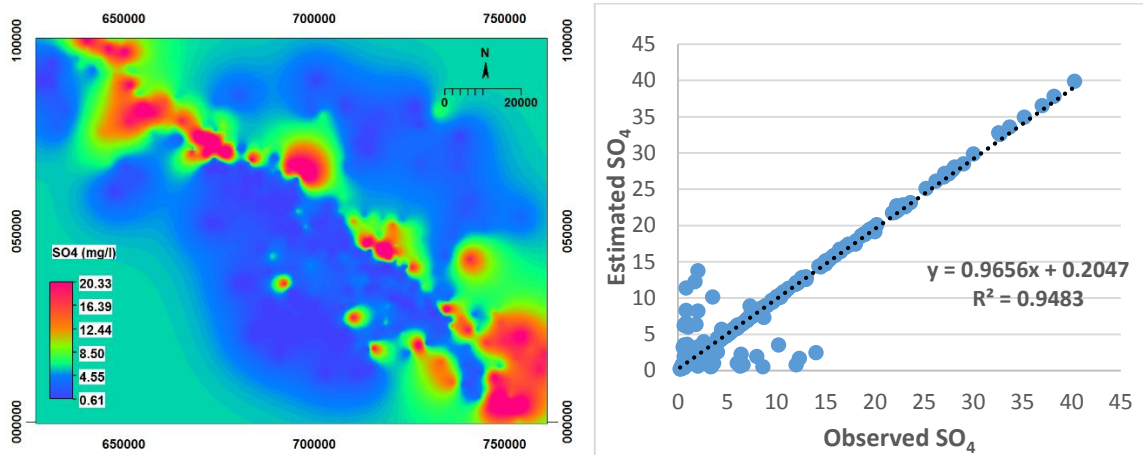


Figure 4.4: Spatial variation of SO_4 in the study area using Kriging (Exponential Model, Nugget=0; Sill=55; Range=5000)

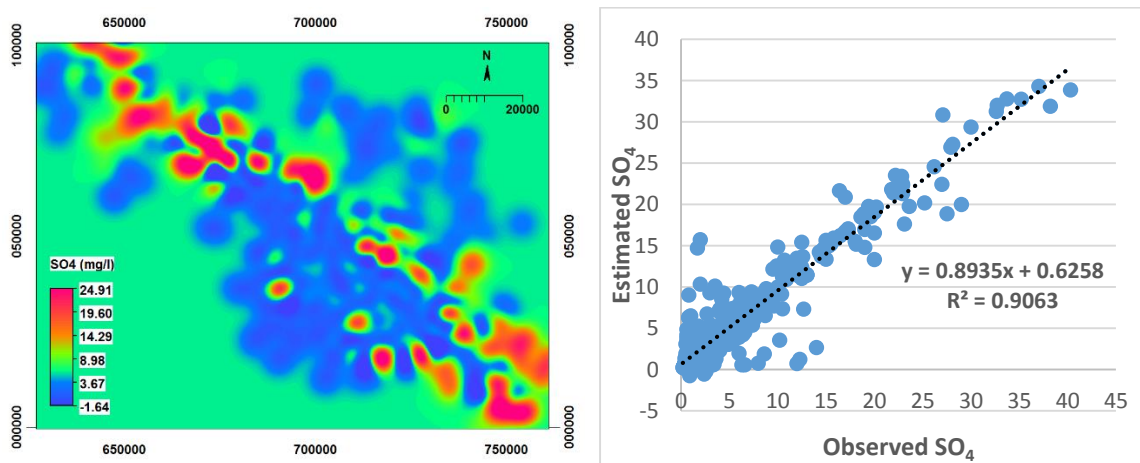


Figure 4.5: Spatial variation of SO_4 in the study area using Kriging (Gaussian Model, Nugget=0; Sill=50; Range=4000)

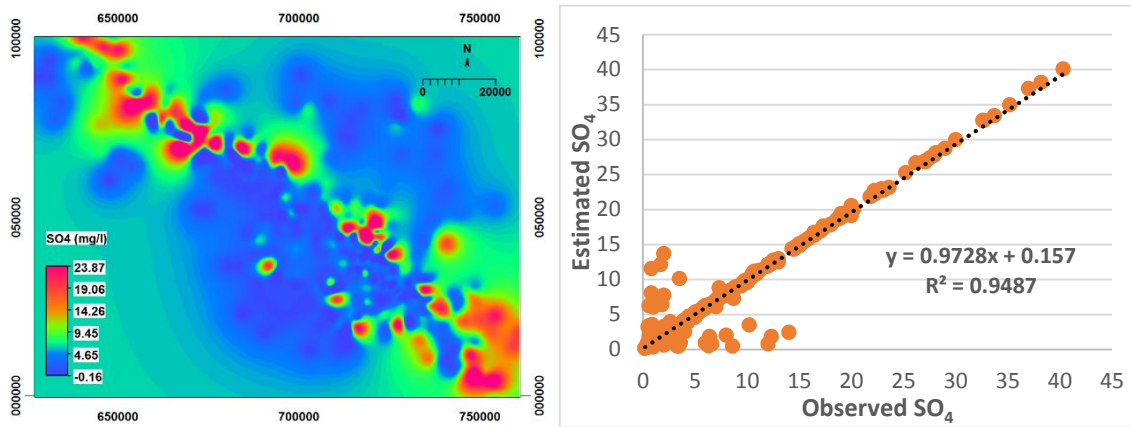


Figure 4.6: Spatial variation of SO_4 in the study area using Kriging (Rational Quadratic Model, Nugget=0; Sill=50; Range=3000)

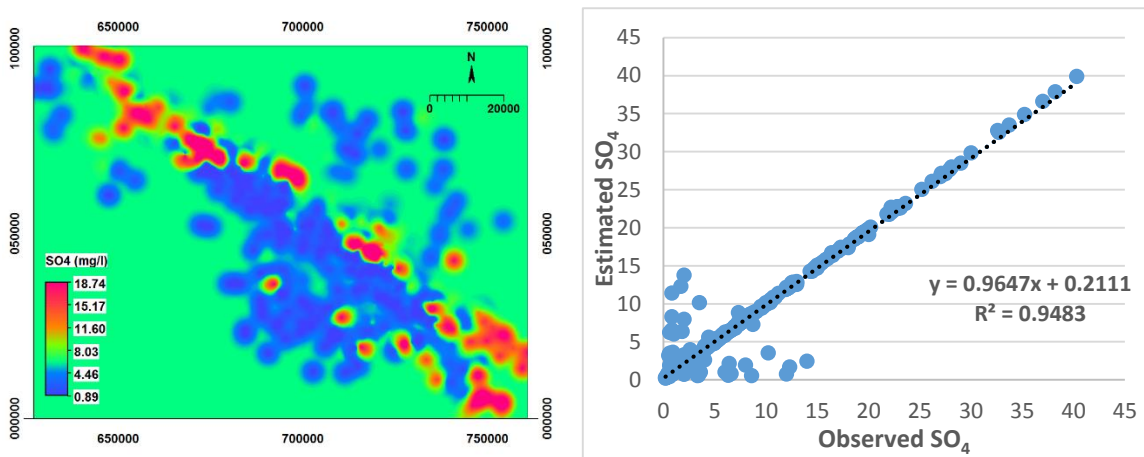


Figure 4.7: Spatial variation of SO_4 in the study area using Kriging (Spherical Model, Nugget=0; Sill=40; Range=5000)

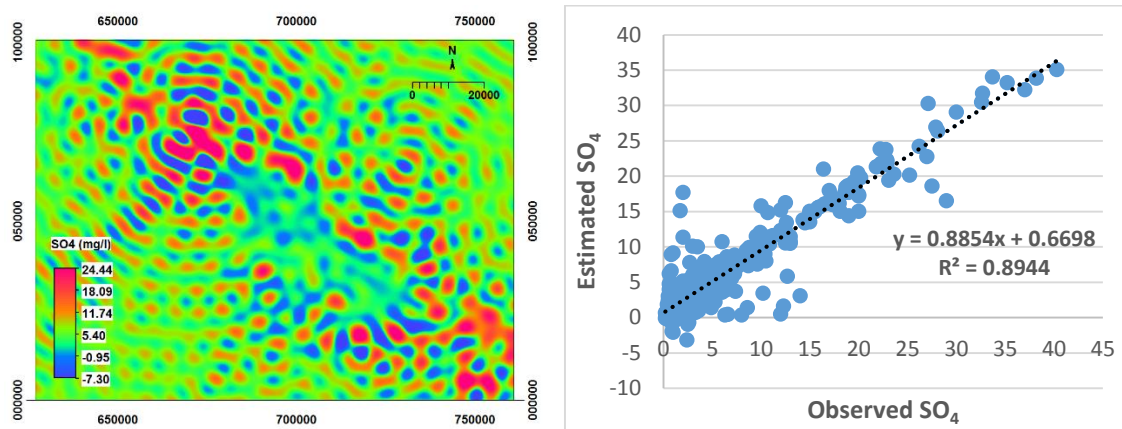


Figure 4.8: Spatial variation of SO_4 in the study area using Kriging (Wave Model, Nugget=1; Sill=40; Range=1000)

pH raster maps:

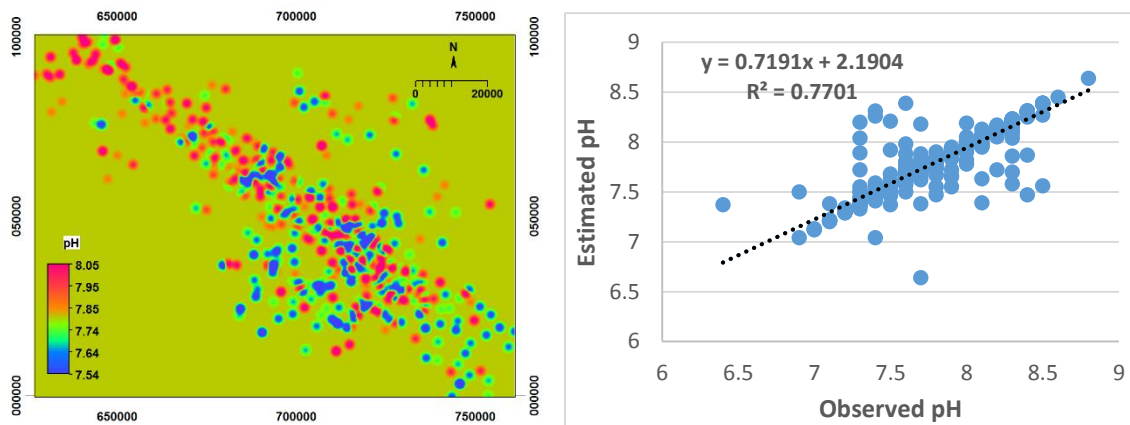


Figure 4.9: Spatial variation of pH in the study area using Kriging (Circular Model, Nugget=0.02; Sill=0.14; Range=2000)

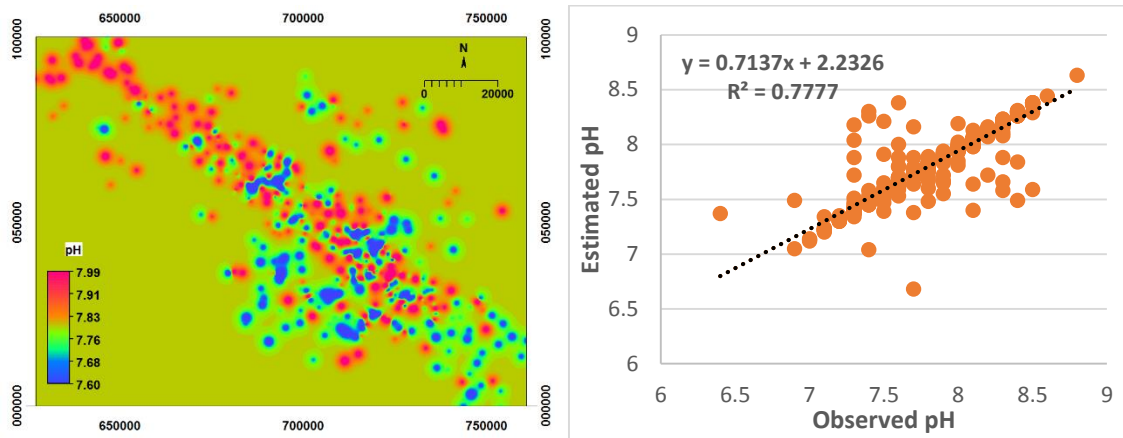


Figure 4.10: Spatial variation of pH in the study area using Kriging (Exponential Model, Nugget=0.02; Sill=0.14; Range=800)

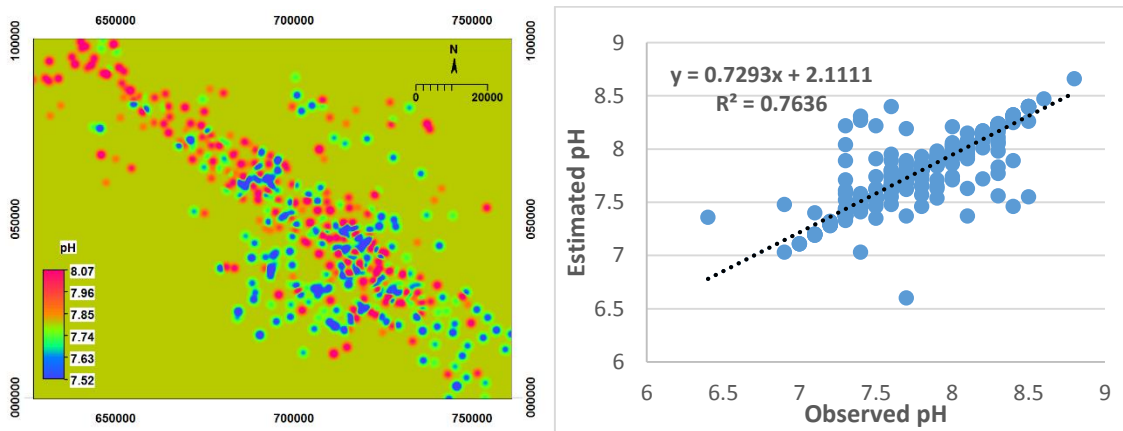


Figure 4.11: Spatial variation of pH in the study area using Kriging (Gaussian Model, Nugget=0.02; Sill=0.14; Range=1000)

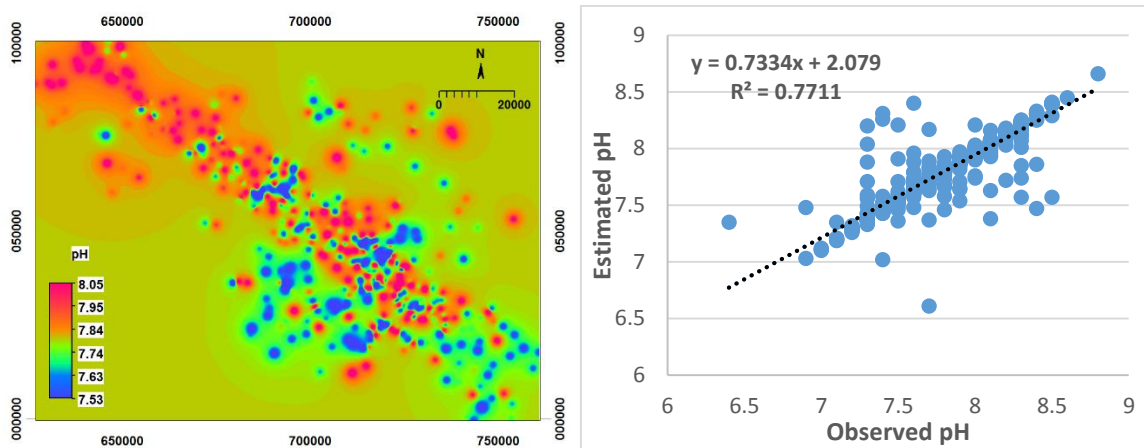


Figure 4.12: Spatial variation of pH in the study area using Kriging (Rational Quadratic Model, Nugget=0.02; Sill=0.14; Range=800)

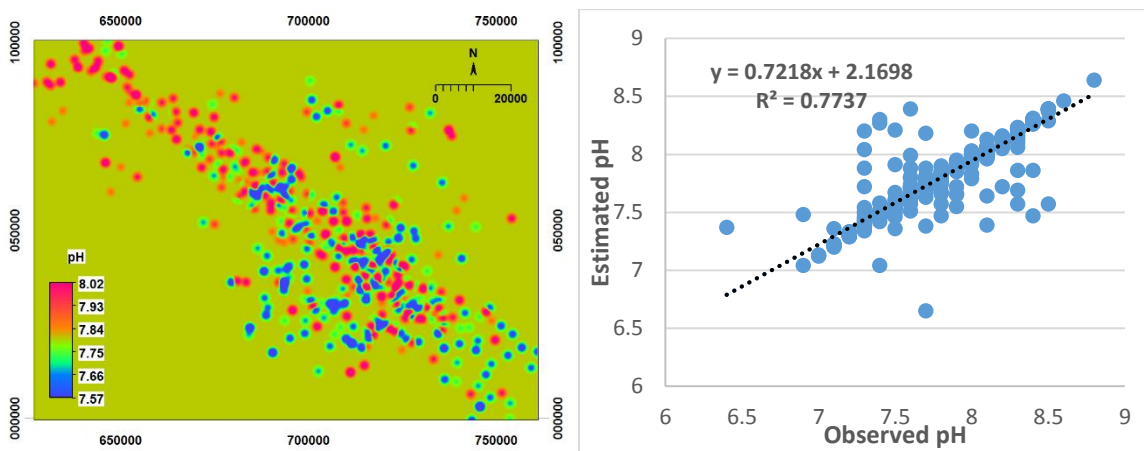


Figure 4.13: Spatial variation of pH in the study area using Kriging (Spherical Model, Nugget=0.02; Sill=0.14; Range=2000)

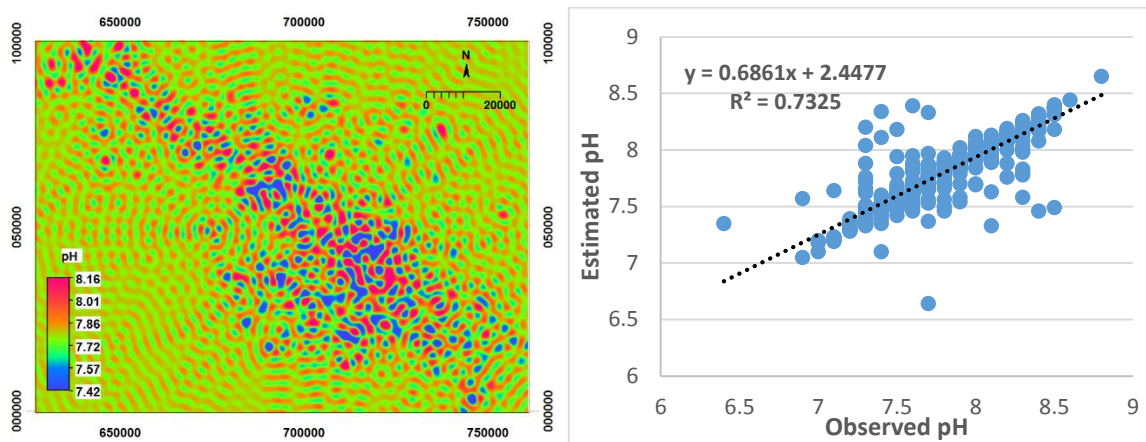


Figure 4.14: Spatial variation of pH in the study area using Kriging (Wave Model, Nugget=0.02; Sill=0.14; Range=500)

There were some noises formed in the scatter plots. This can be explained by many different possibilities. Firstly, there was some calculation error or wrong measurement during the water quality test. Therefore the result obtained was wrong. Next, the existence of different geology section in one area will also affected the graph plotted where the samples may differ from the rest of the samples. Besides, there was some pollution occurred on some specific sample location which may also influenced the scatter plots.

We can discussed these results by two different cases. The first case like noises which falls on top of the linear line can be defined as the estimated value was higher than that of the observed data. This is mainly because the low value sample was surrounded by higher value sample in that area. As a result, the small value sample might be neglected during the spatial interpolation and yet calculated as a higher estimated value due to the majority of the sample with high value.

On the other hand, the second case like noises which falls below the linear line can be indicated as the estimated value was lower than that of the observed data. This is probably due to the high value sample was encompassed by smaller value sample in that area. As a result, the high value sample might be ignored during the spatial interpolation

and yet calculated as a lower estimated value due to the majority of the sample with small value.

After being summarized by doing the error checking, the best fitted model for SO₄ was a Rational Quadratic Model and for pH was Exponential Model. All these evaluations can be done by referring to the Coefficient of determination, R²; Nash–Sutcliffe model efficiency coefficient, E, and root-mean-square deviation, RMSD. The equations for each error measure will be shown as below:

$$R^2 = \left\{ \left(\frac{1}{N} \right) * \Sigma [(x_i - \bar{x}) * (y_i - \bar{y})] / (\sigma_x * \sigma_y) \right\}^2 \quad \text{eqn 4.1}$$

where N is the number of observations used to fit the model, Σ is the summation symbol, x_i is the x value for observation i, \bar{x} is the mean x value, y_i is the y value of observation i, \bar{y} is the mean y value, σ_x is the standard deviation of x, and σ_y is the standard deviation of y.

$$E = 1 - \frac{\sum_{i=1}^n (X_{obs,i} - X_{model})^2}{\sum_{i=1}^n (X_{obs,i} - \overline{X_{obs}})^2} \quad \text{eqn 4.2}$$

where X_{obs} is observed values and X_{model} is modelled values at time/place i . Its definition is identical to the coefficient of determination R^2 used in linear regression.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (X_{obs,i} - X_{model,i})^2}{n}} \quad \text{eqn 4.3}$$

where X_{obs} is observed values and X_{model} is modelled values at time/place i .

Here are the tables for SO₄ and pH regarding their error measure result as below:

Table 4.1: Error measure for SO₄ with 100m lag among different semivariogram models

SO ₄ 100m						
Models	Circular	Exponential	Gaussian	Rational Quadratic	Spherical	Wave
R²	0.9482	0.9483	0.9063	0.9487	0.9483	0.8944
RMSD	1.6660	1.6657	2.2367	1.6629	9.3141	2.3736
E	0.9479	0.9479	0.9061	0.9481	0.9480	0.8943

Table 4.2: Error measure for pH with 100m lag among different semivariogram models

pH 100m						
Models	Circular	Exponential	Gaussian	Rational Quadratic	Spherical	Wave
R²	0.7701	0.7777	0.7636	0.7711	0.7737	0.7325
E	0.7667	0.7725	0.7621	0.7693	0.7702	0.7295
RMSD	0.1792	0.1769	0.1809	0.1782	7.8032	0.1929

In Table 4.1, SO₄ raster map by Rational Quadratic Model has R² equals to 0.9487 which is the biggest value of the others can be determined at the Figure 4.6; E equals to 0.9481 which is the largest among the rest models and RMSD equals to 1.6629 which is the lowest from the others. A higher value or approximately to 1 of R² and E represent the estimation is very accurate to the actual value. In addition, the smallest value of RMSD indicates the high accuracy of prediction. Thus, Rational Quadratic Model is the best fitted model for simple kriging in SO₄.

Furthermore, in Table 4.2, pH raster map by Exponential Model has R² equals to 0.7777 which is the biggest value of the others can be determined at the Figure 4.10; E

equals to 0.7725 which is the largest among the rest models and RMSD equals to 0.1769 which is the lowest from the others. Thus, Exponential Model is the best fitted model for simple kriging in pH because it possesses the highest value of R^2 and E as well as the lowest value of RMSD.

For the next objective that is the accuracy trend with different lag distance by SO_4 and pH, the estimation of SO_4 with 500m can be considered accurate ($R^2 = 0.9558$) and estimation with 1000m lag is moderately accurate ($R^2 = 0.8378$). For the estimation with 1500m, it can be classified into slightly accurate ($R^2 = 0.6903$). The value for R^2 and E is decreasing with distance of lag. All the calculated value can be found in Table 4.3.

Besides that, the trend of the estimation in pH is almost the same as SO_4 that is the farther the distance of lag, the less accurate its estimation. These values also tabulated in Table 4.4 as shown below:

Table 4.3: Error measure of different lag distance of SO_4

SO₄ 100	SO₄ 500	SO₄ 1000	SO₄ 1500
R²	0.9558	0.8378	0.6903
E	0.9544	0.8372	0.6900
RMSD	2.0440	3.8614	5.3288

Table 4.4: Error measure of different lag distance of pH

pH 100	pH 500	pH 1000	pH 1500
R²	0.983	0.9148	0.7644
E	0.6466	0.3570	0.1864
RMSD	0.2422	0.3267	0.3675

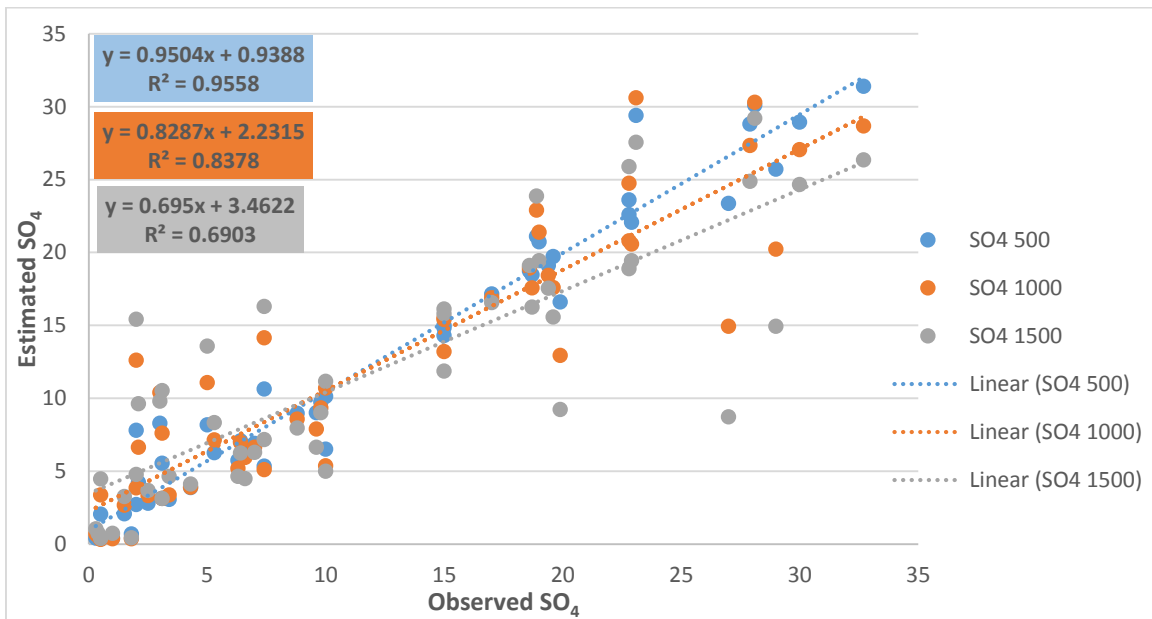


Figure 4.15: Trend line for SO_4 with 500m, 1000m, and 1500m lags

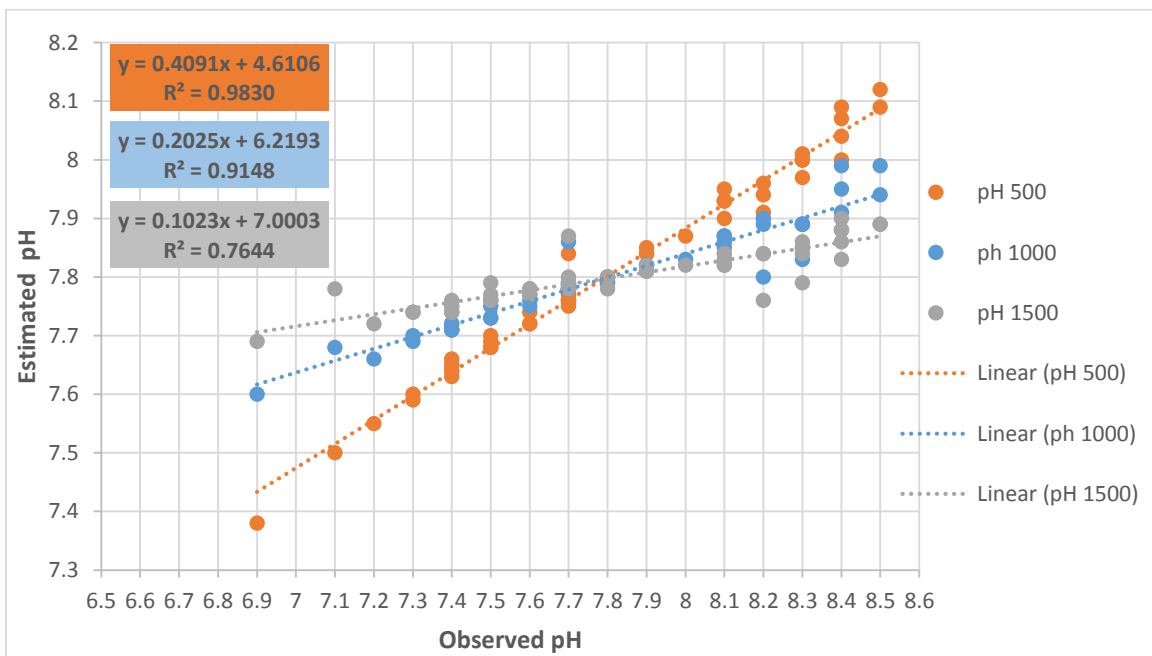


Figure 4.16: Trend line for pH with 500m, 1000m, and 1500m lags

As the lag distance increases, the accuracy of estimation will become poorer. This is because the farther the lag goes, the interceptions of the actual value with other sample value may affect the result where a compact sample location may consist of many interception of values among others. Thus, an optimum lag distance needed to perform a better result.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

All in all, the best fitted model which can produce the most accurate SO₄ quality map is by Rational Quadratic Model whereas Exponential Model is the best model to be used for pH quality map output. There were assessed by 3 different error measure such as Coefficient of determination, R²; Nash–Sutcliffe model efficiency coefficient, E, and root-mean-square deviation, RMSD.

In SO₄, the quality map interpolated by referring Rational Quadratic Model gained the highest value of coefficient of determination and also the Nash Sutcliffe model efficiency coefficient that are R² equal to 0.9487 and E equal to 0.9481 as well the smallest error for root mean square deviation, RMSD equal to 1.6629.

Moreover, the pH quality map which was referring to the Exponential Model obtained the largest value of coefficient of determination and also the Nash Sutcliffe model efficiency coefficient, R² equal to 0.7777 and E equal to 0.7725. It also has the least value of the root mean square deviation that is RMSD equal to 0.1769.

The accuracy of estimation of water quality of kriging method will become lower as the distance of lag increases. The R² for SO₄ with 500m lag distance was decreased from 0.9558 to 0.8378 and then to 0.6903 for SO₄ with 1000m lag and 1500m lag respectively. The E also reduces from 0.9544 to 0.8372 and then to 0.6900 for 500m, 1000m and 1500m lag distance. Only the RMSD value increases, which indicate the predicted value is not accurate anymore for example from 2.0440, 3.8614 and lastly to 5.3288 as the lag distance

risers from 500m, 1000m and 1500m. All these three trend patterns have shown that the accuracy of the water quality mapping was dropped versus the lag distance.

It was also obtained a similar trend pattern for pH quality mapping. The R^2 decreases from 0.983 to 0.9148 and to 0.7644 whereas E reduces from 0.6466 to 0.3570 and lastly 0.1864 as well as RMSD grows from 0.2422 to 0.3267 and then to 0.3675. All the values were referring to the lag distance of 500m, 1000m and 1500m respectively.

Kriging interpolated results are dependent on the selection of semivariogram model largely, and different semivariogram model will lead to different results. The biggest advantage of ILWIS is that it is a compact package with a diverse vector and raster-based GIS functionality. It is a free software for public and thus it is a very convenient tool for GIS analysis. This research contributes to the GIS user in water quality mapping on selection of semivariogram models in kriging method.

For recommendations, the results can be improved by obtaining more sample data together with more water quality parameters, chose the optimum pixel and lag distance for Kriging interpolation, obtained the best semivariogram parameters, and also make sure the concentration of the sample is packed. Besides that, for this study, the choice of a variety of software to perform GIS analysis may help to get the best result by comparing through different software. There is a lot of precaution which must be alert of, for example, have a good and high performance computer, check for the repetition of the sample coordinates, draw the best fitted line of semivariogram and lastly try an error to get the best fitted model map.

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APPENDIX A

Wells Coordinate	No.	SO4	pH
(638000.00, 4095400.00)	1	5.2	8.2
(638900.00, 4093400.00)	2	7	8.4
(647600.00, 4060200.00)	3	0.3	7.9
(661400.00, 4077000.00)	4	8.5	8.1
(677500.00, 4066200.00)	5	0.8	8.2
(679400.00, 4070700.00)	6	9.9	8.3
(695650.00, 4054450.00)	7	5	7.8
(701000.00, 4031200.00)	9	0.7	7.4
(720700.00, 4024900.00)	10	2.7	7.3
(627100.00, 4089100.00)	11	0.7	8
(630550.00, 4089500.00)	12	0.3	8.2
(631600.00, 4088600.00)	13	0.6	8.2
(631650.00, 4094250.00)	14	0.7	8.3
(631900.00, 4078900.00)	15	3.1	7.9
(632750.00, 4077100.00)	17	2.6	7.8
(634200.00, 4089400.00)	18	3.8	8.3
(634850.00, 4081800.00)	19	2	7.9
(640450.00, 4099800.00)	20	22.3	8.3
(640700.00, 4097850.00)	21	12	8.2
(641900.00, 4098400.00)	22	16.5	8.3
(642300.00, 4092350.00)	23	3.7	8.1
(643500.00, 4093200.00)	24	7.6	8.3
(644000.00, 4075800.00)	25	11.9	7.7
(644250.00, 4095150.00)	26	8.7	8.2
(645900.00, 4075400.00)	27	12.5	7.3
(646200.00, 4068000.00)	28	7.4	8.4
(646250.00, 4097800.00)	29	22	7.7

(646500.00, 4090900.00)	30	8.3	8.2
(646650.00, 4100550.00)	31	7	7.7
(647800.00, 4090700.00)	32	12	8.8
(648400.00, 4091550.00)	33	10.9	7.9
(649700.00, 4099000.00)	34	11.2	8.5
(650300.00, 4066800.00)	35	1.5	7.9
(650500.00, 4097000.00)	36	22.9	7.7
(651200.00, 4092500.00)	37	7.9	8.3
(651600.00, 4078400.00)	38	19.6	7.9
(652000.00, 4088100.00)	39	22.9	8.1
(652500.00, 4084000.00)	40	14.3	7.9
(652600.00, 4091400.00)	41	7.5	8.2
(652900.00, 4086660.00)	42	10.4	8
(654400.00, 4086000.00)	43	7	8.5
(654700.00, 4064200.00)	44	1.8	8.1
(655300.00, 4082700.00)	45	26.2	7.3
(655300.00, 4082900.00)	46	22.2	8
(657300.00, 4084300.00)	47	12.6	8
(657500.00, 4084250.00)	48	14.5	7.8
(658000.00, 4075850.00)	49	6	7.9
(658100.00, 4080300.00)	52	19.4	8.3
(658400.00, 4080500.00)	53	20.2	7.5
(661200.00, 4084000.00)	54	15.5	8.1
(661500.00, 4077000.00)	56	10.4	7.8
(663750.00, 4076700.00)	57	6.9	8.2
(664200.00, 4085100.00)	58	6	8.1
(664500.00, 4081450.00)	59	10.5	7.9
(664800.00, 4081500.00)	60	12	8.2
(665100.00, 4074200.00)	61	2	8.3
(665400.00, 4078600.00)	62	18.9	8.1

(668200.00, 4070850.00)	63	20	7.4
(668250.00, 4071300.00)	64	4.4	7.8
(669600.00, 4070700.00)	65	10.7	8
(669700.00, 4081300.00)	66	8.4	8.3
(670300.00, 4074800.00)	67	35.2	7.9
(670400.00, 4074700.00)	68	33.7	7.8
(671200.00, 4072100.00)	69	17	7.1
(671300.00, 4076800.00)	70	7.3	8.2
(671800.00, 4066700.00)	72	1	8.2
(671900.00, 4070050.00)	73	25.2	7.7
(672250.00, 4052100.00)	74	0.4	7.6
(673900.00, 4073400.00)	76	40.3	7.9
(674250.00, 4076200.00)	77	5	8.3
(674400.00, 4073100.00)	78	27.1	8.1
(674650.00, 4083500.00)	79	4.1	7.7
(675050.00, 4064500.00)	80	2	7.6
(675100.00, 4080100.00)	81	7.6	8.2
(675200.00, 4051600.00)	82	0.5	8
(676000.00, 4074650.00)	83	12.5	7.5
(676000.00, 4077540.00)	84	9.8	7.8
(676100.00, 4067500.00)	85	0.9	7.7
(676300.00, 4072200.00)	86	16.4	7.9
(676700.00, 4086400.00)	87	4.1	7.9
(676800.00, 4072400.00)	88	17.3	7.8
(676900.00, 4073400.00)	89	8.3	8.1
(677100.00, 4061400.00)	92	0.8	8
(677100.00, 4070600.00)	93	38.2	8.1
(677700.00, 4064200.00)	94	1.3	7.9
(679050.00, 4064300.00)	95	2	7.7
(679800.00, 4036200.00)	96	0.5	7.3

(679850.00, 4071400.00)	97	5	7.8
(680500.00, 4085300.00)	98	2	8.1
(680650.00, 4067000.00)	99	0.7	7.6
(681150.00, 4036500.00)	100	0.3	8.2
(681300.00, 4065900.00)	101	0.9	7.7
(681400.00, 4071150.00)	102	2.3	7.7
(681600.00, 4058600.00)	103	0.7	7.7
(681700.00, 4058800.00)	104	0.7	8.1
(682100.00, 4063100.00)	105	0.6	7.9
(682400.00, 4062850.00)	106	0.6	7.7
(682400.00, 4073400.00)	107	5.5	7.9
(682700.00, 4062000.00)	108	0.8	7.8
(683100.00, 4067900.00)	109	4.3	8.2
(683300.00, 4060250.00)	110	0.5	8.2
(683600.00, 4036200.00)	112	0.4	8.2
(683700.00, 4068500.00)	113	23.1	8.1
(683750.00, 4062900.00)	114	0.8	7.9
(684350.00, 4022250.00)	115	0.2	7.6
(684650.00, 4024050.00)	116	0.2	7.1
(685100.00, 4060200.00)	118	1.7	7.3
(685350.00, 4056400.00)	119	0.8	7.6
(685400.00, 4065400.00)	120	0.7	8.3
(685800.00, 4055800.00)	121	0.8	8
(686000.00, 4059200.00)	122	0.8	7.3
(686100.00, 4061800.00)	123	0.6	8.3
(686400.00, 4071600.00)	124	6.2	8.2
(686700.00, 4045200.00)	125	0.9	7.6
(686800.00, 4059250.00)	126	1	7.1
(687100.00, 4065350.00)	127	2	7.9
(687500.00, 4061100.00)	128	2	7.3

(687850.00, 4071000.00)	129	9.6	7.9
(688000.00, 4049150.00)	130	1.7	7.8
(688400.00, 4039100.00)	131	0.8	7.2
(688550.00, 4032000.00)	132	0.5	7.5
(688800.00, 4059200.00)	133	0.4	8.2
(688950.00, 4027400.00)	134	0.3	7.3
(689150.00, 4056400.00)	135	0.8	7.9
(689200.00, 4043200.00)	136	6.6	7.5
(689400.00, 4029400.00)	137	0.4	7.5
(689600.00, 4061800.00)	138	1.5	7.5
(689600.00, 4069300.00)	139	2.3	8.1
(689850.00, 4064850.00)	140	3.5	7.4
(690200.00, 4055300.00)	141	0.5	8.2
(690200.00, 4060750.00)	142	1.2	7.4
(690300.00, 4057200.00)	143	0.7	8.3
(690600.00, 4049600.00)	144	0.8	7.9
(690700.00, 4017450.00)	145	0.3	7.1
(690700.00, 4062500.00)	146	1.5	8.2
(691000.00, 4068750.00)	147	5	7.3
(691150.00, 4065200.00)	148	3.4	7.6
(691200.00, 4039250.00)	149	2.7	7.7
(692250.00, 4039300.00)	150	2.8	7.5
(692250.00, 4047350.00)	151	2.8	7.9
(692400.00, 4036100.00)	152	19	7.9
(692450.00, 4057000.00)	153	0.6	7.6
(692500.00, 4024600.00)	154	0.4	7.8
(692500.00, 4061350.00)	155	2	7
(692900.00, 4058000.00)	156	0.5	8.3
(693000.00, 4052400.00)	157	0.9	7.7
(693200.00, 4065400.00)	158	18.1	8.2

(693400.00, 4049150.00)	159	0.8	7.4
(693650.00, 4036000.00)	160	8.6	6.4
(693700.00, 4034150.00)	161	0.4	7.3
(693700.00, 4046750.00)	162	0.8	7.9
(693700.00, 4067700.00)	163	21.8	8.1
(693850.00, 4025950.00)	164	0.6	7.7
(693900.00, 4059300.00)	165	1	7.2
(694250.00, 4055900.00)	166	0.7	7.7
(694250.00, 4061500.00)	167	1.3	7.4
(694450.00, 4039700.00)	168	1.7	7.3
(694950.00, 4037400.00)	169	2.9	7.6
(695100.00, 4051900.00)	170	0.4	8.2
(695200.00, 4040600.00)	171	2.1	7.4
(695300.00, 4021250.00)	172	0.4	7.4
(695300.00, 4034100.00)	173	0.8	7.8
(695300.00, 4060500.00)	174	1.5	8
(695600.00, 4058000.00)	175	0.7	7.6
(695700.00, 4066450.00)	176	22.8	7.1
(695750.00, 4063600.00)	177	1.8	7.3
(695800.00, 4055200.00)	178	6.4	8.1
(695970.00, 4028750.00)	179	0.9	8.4
(696100.00, 4047600.00)	180	1.7	8
(696700.00, 4050350.00)	181	0.5	7.4
(697600.00, 4065250.00)	182	28.1	8.2
(697950.00, 4051000.00)	184	6	7.4
(698300.00, 4064100.00)	185	27.9	8.1
(699100.00, 4040900.00)	186	4.9	7.3
(699250.00, 4022550.00)	187	0.6	7.4
(699300.00, 4031800.00)	188	0.7	7.7
(699400.00, 4025950.00)	189	0.6	7.6

(699600.00, 4050550.00)	190	2.9	8
(699600.00, 4051500.00)	191	0.7	7.5
(699700.00, 4054600.00)	192	2.6	7.5
(699750.00, 4037050.00)	193	3.1	7.4
(699750.00, 4081500.00)	194	2.1	8
(699850.00, 4045100.00)	195	0.7	7.5
(699900.00, 4049200.00)	196	1.4	7.8
(699950.00, 4033750.00)	197	3.1	7.9
(700200.00, 4059600.00)	198	7	8.1
(700250.00, 4054550.00)	199	3	8.2
(700450.00, 4059550.00)	200	7	7.6
(700600.00, 4047000.00)	201	0.8	8
(700650.00, 4089750.00)	202	0.7	7.7
(700900.00, 4048400.00)	203	1.5	7.4
(701100.00, 4084700.00)	204	3.1	7.4
(702000.00, 4028950.00)	205	0.9	7.4
(702350.00, 4080250.00)	206	7	7.4
(702550.00, 4024400.00)	207	0.4	8.3
(702550.00, 4052500.00)	208	0.5	7.9
(702850.00, 4012500.00)	209	0.3	7.6
(703100.00, 4043850.00)	210	2.8	8.2
(703600.00, 4030650.00)	211	1.9	7.7
(704100.00, 4043200.00)	212	1	8.2
(704300.00, 4056700.00)	213	1	7.4
(704350.00, 4026700.00)	214	0.9	7.6
(704600.00, 4045250.00)	215	0.5	7.7
(705300.00, 4081800.00)	219	4.1	7.4
(705850.00, 4047400.00)	220	1.5	7.6
(705950.00, 4019150.00)	221	0.4	7.5
(706050.00, 4030450.00)	222	1.6	7.1

(706750.00, 4046250.00)	223	1	7.5
(706850.00, 4055050.00)	224	6	7.4
(706900.00, 4052400.00)	225	1	8.4
(706950.00, 4028550.00)	226	2.1	7.4
(707200.00, 4022250.00)	227	0.5	7.7
(707300.00, 4040200.00)	228	1.5	8.4
(707350.00, 4069500.00)	229	6.3	8.5
(707500.00, 4031200.00)	230	3	7.5
(707750.00, 4027900.00)	231	4.3	7.7
(707750.00, 4058750.00)	232	7	7.5
(707850.00, 4029950.00)	233	0.9	7.4
(708200.00, 4043100.00)	234	4.5	7.5
(708200.00, 4081900.00)	235	1.1	7.7
(708250.00, 4083300.00)	236	1.1	8.2
(708350.00, 4045450.00)	237	0.8	8.3
(708700.00, 4024150.00)	238	0.9	7.7
(709200.00, 4030500.00)	239	3.7	7.6
(709300.00, 4030350.00)	240	1.7	7.3
(709400.00, 4034400.00)	241	0.9	7.6
(709400.00, 4046550.00)	242	1.3	7.6
(709400.00, 4057400.00)	243	5.7	8
(709950.00, 4030750.00)	244	1.9	7.3
(710200.00, 4044450.00)	245	1.5	8.3
(710250.00, 4021100.00)	246	0.8	7.2
(710300.00, 4036900.00)	247	3.9	8.3
(710300.00, 4078450.00)	248	2.5	8
(710400.00, 4052400.00)	249	13	8.5
(710450.00, 4027150.00)	250	19.6	8.3
(710500.00, 4032850.00)	251	2.5	7.9
(711350.00, 4041750.00)	252	3.3	7.6

(711400.00, 4012200.00)	253	0.5	8.5
(711500.00, 4072750.00)	254	0.9	7.6
(711750.00, 4041700.00)	255	2.6	7.4
(711800.00, 4019900.00)	256	4	6.9
(712000.00, 4048100.00)	257	12	7.4
(712150.00, 4024400.00)	258	5	7.5
(712200.00, 4065800.00)	259	3.3	7.8
(712250.00, 4034900.00)	260	3.6	8
(712250.00, 4044750.00)	261	1.5	8.3
(712800.00, 4040500.00)	262	0.7	8.6
(713000.00, 4041900.00)	263	2.6	7.5
(713250.00, 4054000.00)	264	4.4	7.7
(713650.00, 4036900.00)	265	4.9	7.3
(713900.00, 4035350.00)	266	1.6	7.6
(713950.00, 4040650.00)	267	1.3	7.5
(714000.00, 4046300.00)	268	29	7
(714050.00, 4034250.00)	269	1	7.2
(714100.00, 4040200.00)	270	1	7.7
(714200.00, 4048700.00)	271	12.5	8.4
(714450.00, 4018850.00)	272	1.3	7.2
(714550.00, 4071150.00)	273	0.6	7.6
(714600.00, 4044700.00)	274	2	8.1
(714750.00, 4034850.00)	275	1	8
(714850.00, 4044900.00)	276	1	7.6
(714900.00, 4076750.00)	277	0.8	7.9
(715100.00, 4014050.00)	278	0.5	8.3
(715100.00, 4041750.00)	279	2.4	7.2
(715435.00, 4038200.00)	280	1	8.4
(715500.00, 4021850.00)	281	3	7.6
(715550.00, 4031600.00)	282	3	7.2

(715600.00, 4056000.00)	283	5.3	8.1
(715650.00, 4038800.00)	284	0.8	7.7
(715750.00, 4019100.00)	287	20	7.9
(715800.00, 4039800.00)	288	1.1	7.7
(715800.00, 4053100.00)	289	9	8.2
(716000.00, 4023200.00)	290	2.6	7.5
(716000.00, 4033900.00)	291	2	7.7
(716000.00, 4034500.00)	294	1.1	8.4
(716250.00, 4021100.00)	295	5.2	7.4
(716700.00, 4048800.00)	296	7.4	8.3
(716950.00, 4024400.00)	297	2.5	8.3
(716950.00, 4047150.00)	298	14	7.3
(717000.00, 4022150.00)	299	2	7.5
(717250.00, 4022150.00)	300	2.9	8.3
(717350.00, 4039450.00)	301	0.9	7.6
(717450.00, 4037100.00)	302	2.5	7.6
(717450.00, 4047750.00)	303	8	7.4
(717500.00, 4041000.00)	304	2	8.4
(717500.00, 4041600.00)	305	2	7.8
(717600.00, 4035250.00)	306	1.2	7.3
(717600.00, 4080550.00)	307	1.4	7.9
(717650.00, 4026400.00)	308	3.2	7.7
(717800.00, 4037000.00)	309	2.3	8
(717800.00, 4045500.00)	310	32.6	8.3
(718050.00, 4045150.00)	311	37	7.1
(718100.00, 4053200.00)	312	5.4	7.9
(718150.00, 4035400.00)	313	3.8	7.4
(718300.00, 4036250.00)	314	2.4	7.5
(718450.00, 4036050.00)	315	2	7.6
(718500.00, 4024750.00)	316	3.2	7.6

(718650.00, 4024300.00)	317	2	7.3
(718650.00, 4037500.00)	318	2.4	8.4
(718800.00, 4041500.00)	319	2	7.3
(718900.00, 4025700.00)	320	6.6	7.4
(719300.00, 4027300.00)	321	4.9	7.9
(719350.00, 4036300.00)	322	3	8.1
(719500.00, 4035100.00)	323	2	7.6
(719700.00, 4027500.00)	324	3.9	8.2
(719700.00, 4030550.00)	325	5.2	7.9
(719750.00, 4041200.00)	326	1.4	7.6
(719800.00, 4042900.00)	327	23.6	7
(720050.00, 4036700.00)	328	3.4	7.6
(720400.00, 4031850.00)	329	0.6	8
(720750.00, 4039100.00)	330	1	7.4
(720750.00, 4072500.00)	331	3.1	7.5
(720950.00, 4051450.00)	332	15	8.1
(721300.00, 4036200.00)	333	3.4	8
(721400.00, 4036600.00)	335	2.6	7.9
(721450.00, 4043500.00)	336	10	7.3
(721500.00, 4046300.00)	337	9.5	8
(721500.00, 4046500.00)	338	13	7.3
(721550.00, 4041950.00)	339	4	8.2
(721850.00, 4023950.00)	340	2	8.3
(722000.00, 4052450.00)	341	6.7	7.7
(722075.00, 4034000.00)	342	1.9	7.8
(722100.00, 4043500.00)	343	13	8.1
(722550.00, 4041450.00)	344	12	8
(722625.00, 4032700.00)	345	0.8	8.3
(722950.00, 4030950.00)	346	0.9	7.7
(722950.00, 4041400.00)	347	7	7.4

(722950.00, 4056800.00)	348	5	8.3
(723100.00, 4024300.00)	349	2.4	7.8
(723200.00, 4052550.00)	350	5	7.8
(723500.00, 4034800.00)	351	2.3	8.5
(723600.00, 4039150.00)	352	2.2	7.8
(723700.00, 4057700.00)	353	4.7	7.8
(723900.00, 4030400.00)	354	0.4	8.3
(723900.00, 4033050.00)	355	2.1	7.5
(724000.00, 4038200.00)	356	2	8.3
(724000.00, 4039900.00)	357	3	7.7
(724150.00, 4028850.00)	358	2.3	7.5
(724150.00, 4030450.00)	359	0.6	8
(724150.00, 4047950.00)	360	10	7.2
(724300.00, 4035900.00)	361	2.8	8.4
(724450.00, 4035250.00)	362	3.9	8
(724500.00, 4039900.00)	363	10.5	7.3
(724600.00, 4040400.00)	366	3	8.2
(724700.00, 4022650.00)	367	7.3	7.4
(724750.00, 4050650.00)	368	9.1	7.3
(725050.00, 4030200.00)	369	0.6	7.6
(725100.00, 4018150.00)	370	3.4	7.9
(725200.00, 4033650.00)	371	2.8	7.5
(725300.00, 4034450.00)	372	1.2	7.7
(725750.00, 4031900.00)	373	1.2	7.9
(725800.00, 4040400.00)	374	19	8.4
(726000.00, 4026600.00)	375	1.8	8.2
(726050.00, 4029825.00)	376	0.7	7.8
(726250.00, 4029700.00)	377	1.7	7.5
(726300.00, 4021050.00)	378	12.3	7.4
(726600.00, 4036450.00)	379	2.7	7.8

(726950.00, 4028450.00)	380	1.3	8.5
(727000.00, 4029000.00)	381	1	7.6
(727000.00, 4035500.00)	382	1.5	8.4
(727150.00, 4082750.00)	383	0.3	8
(727300.00, 4030525.00)	384	2.6	7.5
(727500.00, 4028525.00)	385	1.8	8
(727550.00, 4076700.00)	386	2.9	8.1
(727700.00, 4020050.00)	390	27	8.1
(727700.00, 4042200.00)	393	8.8	7.5
(727750.00, 4027250.00)	394	1	7.5
(727800.00, 4077350.00)	395	0.5	7.8
(727850.00, 4029850.00)	396	2.1	7.6
(727925.00, 4027900.00)	397	1.7	7.8
(728100.00, 4067200.00)	398	2	7.5
(728250.00, 4028525.00)	399	2	7.8
(728300.00, 4049800.00)	400	6.5	7.4
(728575.00, 4030750.00)	401	4	7.5
(728800.00, 4047800.00)	402	5.7	7.4
(728850.00, 4029300.00)	403	2	7.3
(729025.00, 4035250.00)	404	8.6	7.7
(729500.00, 4020250.00)	405	4.3	7.4
(729500.00, 4030500.00)	406	1.8	7.8
(729600.00, 4020500.00)	407	2.8	7.5
(729850.00, 4031750.00)	408	1.3	7.7
(729900.00, 4026350.00)	409	2.2	8.2
(730150.00, 4029700.00)	410	1.1	7.5
(730700.00, 4034500.00)	411	6.3	8.4
(730800.00, 4026600.00)	412	1.9	8.3
(731150.00, 4026850.00)	413	2	7.9
(731825.00, 4039150.00)	414	4.3	7.7

(732400.00, 4028950.00)	415	1.1	7.7
(732600.00, 4081200.00)	416	7.8	7.6
(732700.00, 4034550.00)	417	3.3	7.6
(733000.00, 4030650.00)	418	8.7	7.6
(733050.00, 4035500.00)	419	4.2	7.7
(733150.00, 4026550.00)	420	2.5	7.7
(733350.00, 4027950.00)	421	1.8	7.9
(733500.00, 4015700.00)	422	15	8.1
(734000.00, 4031400.00)	423	5.7	7.6
(734800.00, 4022600.00)	424	3.4	7.2
(734850.00, 4024350.00)	425	2	7.8
(734850.00, 4027100.00)	426	1.9	7.9
(734900.00, 4029300.00)	427	27.5	8.2
(734900.00, 4033900.00)	428	4	7.9
(735250.00, 4031600.00)	429	4.2	7.6
(735500.00, 4033600.00)	430	3	8.1
(735700.00, 4027650.00)	431	6	7.7
(735800.00, 4023500.00)	432	3.9	8.1
(735800.00, 4062700.00)	433	3	7.5
(736100.00, 4026500.00)	434	2.5	8.2
(736200.00, 4025100.00)	435	12.7	7.6
(736300.00, 4018600.00)	438	4.3	7.2
(736500.00, 4010300.00)	439	15.3	7.4
(737450.00, 4051050.00)	440	3	7.6
(737550.00, 4076700.00)	441	3	8.4
(738100.00, 4067200.00)	442	1.6	7.8
(738600.00, 4026800.00)	443	14.7	8.1
(739600.00, 4009700.00)	444	1.8	7.7
(739600.00, 4055250.00)	445	1.8	7.9
(739800.00, 4014800.00)	446	2.3	7.6

(740400.00, 4019800.00)	447	3.8	7.4
(740400.00, 4031400.00)	448	8.1	8.3
(740700.00, 4023900.00)	449	19.9	7.7
(741000.00, 4042500.00)	450	18.7	7.4
(741650.00, 4058550.00)	451	2	7.9
(741900.00, 4028000.00)	452	4	7.5
(743000.00, 4024100.00)	453	5.2	7.7
(743400.00, 4006400.00)	454	3.1	8.1
(743700.00, 3999500.00)	455	9.8	7.4
(744000.00, 4012900.00)	456	2.1	7.8
(744750.00, 4050900.00)	457	3.5	7.7
(744800.00, 4018100.00)	458	10.2	7.3
(745300.00, 4020600.00)	459	17.3	7.5
(745400.00, 4008600.00)	460	7.4	7.6
(745800.00, 4027000.00)	461	6	7.7
(745900.00, 4003100.00)	462	18.9	6.9
(747450.00, 4011600.00)	463	22.8	7.4
(747600.00, 4028350.00)	464	12.2	8.3
(748400.00, 4029300.00)	465	7.9	7.5
(748600.00, 4005500.00)	466	32.7	7.5
(748900.00, 4014400.00)	467	5.3	7.5
(749000.00, 4025950.00)	468	16	7.9
(749900.00, 4020800.00)	470	18.6	8.3
(751500.00, 4024600.00)	471	15.8	7.4
(753300.00, 4016700.00)	472	17	7.4
(753800.00, 3999800.00)	473	10	7.7
(753900.00, 4004000.00)	474	30	7.6
(754300.00, 4053150.00)	475	2.9	8.2
(754550.00, 4022350.00)	476	22.9	7.4
(757000.00, 4018800.00)	477	15	7.3

(759500.00, 4013400.00)	478	19.4	7.5
(761200.00, 4017700.00)	479	19.4	7.4
(644300.00, 4094300.00)	480	7.3	8.1
(673900.00, 4068900.00)	481	2.2	8
(689400.00, 4065400.00)	482	5.3	8.1
(693650.00, 4049150.00)	483	0.8	7.7
(701500.00, 4029800.00)	484	1	8.3
(704000.00, 4055200.00)	485	1.5	8.5
(704800.00, 4048900.00)	486	1.2	8.5
(705230.00, 4051000.00)	487	2	7.8
(708250.00, 4050150.00)	488	1.4	7.7
(708650.00, 4066750.00)	489	3.6	7.9
(709500.00, 4054750.00)	490	6.5	8.1
(709700.00, 4047800.00)	491	1.8	8.2
(714800.00, 4047950.00)	492	20	7.3
(719700.00, 4032450.00)	493	1.3	8.4
(721550.00, 4044100.00)	495	18	7.2
(723250.00, 4031550.00)	496	0.6	7.5
(723300.00, 4023150.00)	497	6.3	8.3
(729100.00, 4026450.00)	498	2	8.1
(732100.00, 4029200.00)	499	1.1	8.3
(734800.00, 4043450.00)	500	2	7.9
(736900.00, 4048600.00)	501	2.5	7.8
(738350.00, 4075150.00)	502	0.3	8.2
(751700.00, 4006700.00)	504	15	8.1